

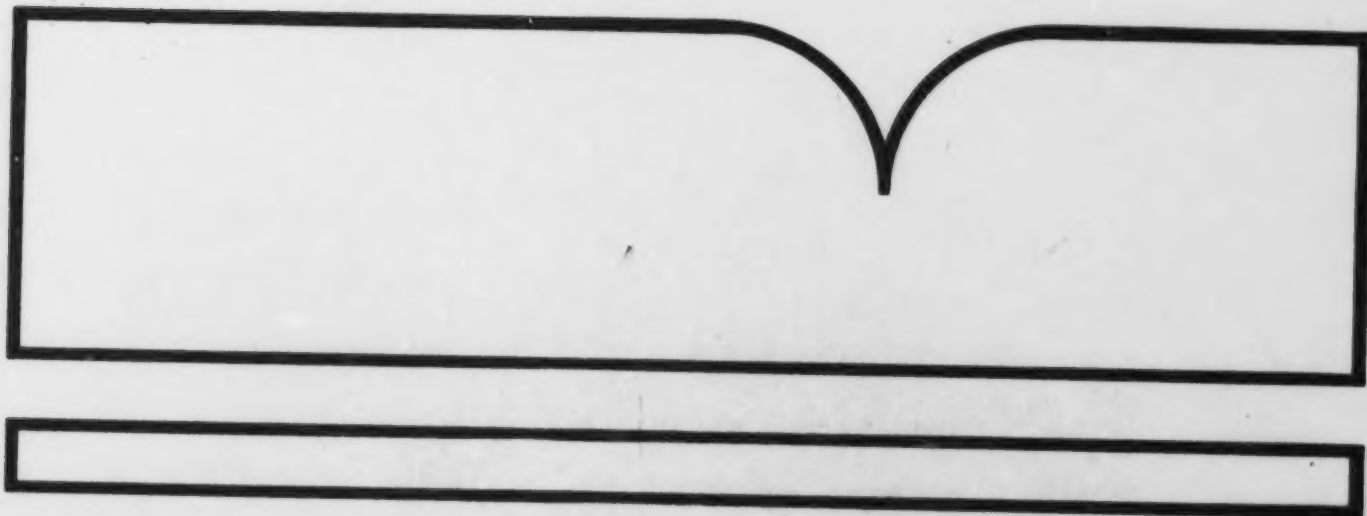
Development of Basic Data and Knowledge
Regarding Organic Removal Capabilities of
Commercially Available Home Water Treatment
Units Utilizing Activated Carbon: Phase 3

Gulf South Research Inst.
New Orleans, LA

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DEVELOPMENT OF BASIC DATA AND KNOWLEDGE REGARDING ORGANIC REMOVAL
CAPABILITIES OF COMMERCIALY AVAILABLE HOME WATER TREATMENT UNITS
UTILIZING ACTIVATED CARBON

Phase 3/Final Report

Submitted to:

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16. ABSTRACT

An extensive study of commercially available home water treatment units has been conducted over a 3-year period to examine organics reduction and microbiological factors. The Phase 3/Final report provides a summary of Phase 1 and 2 results as well as detailed reporting of Phase 3. Phase 3 included the testing of 10 selected activated carbon units against a ground water spiked with carbon tetrachloride, trichloroethylene, tetrachloroethylene and 1,1,1-trichloroethane and of the same units against a surface water spiked with the above and with p-dichlorobenzene, hexachlorobenzene and chlordane; field studies (Miami, Fla.; Pico Rivera, Calif.; Atlanta, Ga.; and Detroit, Mi.) on four units; home tests on three units; bacterial leaching studies; spent carbon studies; and studies of limited value on four other units (reverse osmosis, ozonator, ultraviolet). Test data on two distillers had to be discarded because of technical problems.

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FOREWORD

In response to public concern over organics in drinking water, EPA has contracted with GSRI to develop basic data and information on the performance of a variety of small home water treatment units with respect to removal of organics and to their bacterial/endotoxin aspects. Previous Phase 1 and Phase 2 reports have covered the laboratory testing of 31 carbon filter units. The following report provides a final summarization of the previous work as well as details regarding Phase 3 testing. Included are home, field (Miami, Florida; Detroit, Michigan; Atlanta, Georgia and Pico Rivera, California), bacterial leaching, ground, and surface water spiking studies.

The use of the organic carrier solvents (hexane and methanol) in the surface water studies of Phase 3 have produced questionable microbiological and chemical reduction results. EPA has decided that the microbiological data and the distiller test results are essentially uninterpretable and they have been excluded from the report. While questionable to some degree, the other surface water data are considered potentially usable with reservation and are included in a separate Addendum.

The Water Quality Improvement Standards and Certification Council (WQISCC), an organization representing water filter manufacturers, has reviewed and consulted on the project as it has proceeded. A representative of the faucet-unit manufacturers has also reviewed the Phase 3 report. WQISCC has requested that it be made clear that many, if not most, of the test units have not been designed to remove the trihalomethanes and other organic chemical or microbiological parameters being measured. Most of the activated carbon home water treatment units have been designed to remove taste and odor only. In this study, some have been tested beyond their claims because consumers and responsible government bodies have a need to know their efficacy for organics removal.

This Phase 3 and Final Report concludes the Gulf South Research Institute contract. However, further limited studies using the Phase 3 protocol, may be arranged at the expense of the involved manufacturers to fill the distillers' data gap; any resultant reports and data will be made available to interested parties.

Nothing in this report should be construed as recommending or endorsing any units; it should be used for informational purposes only.

Frank A. Bell, Jr.
Project Officer

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SECTION 1

INTRODUCTION

Recently detected drinking water contamination by synthetic organic chemicals and other pollutants in a number of locations is a matter of concern to many communities and people. The majority of identified compounds are low-molecular-weight volatile or semivolatile chlorinated compounds, pesticides, and herbicides. Problems have occurred with trichloroethylene, carbon tetrachloride, tetrachloroethylene, 1,1,1-trichloroethane and other chemical contaminants, particularly in groundwaters but also in surface waters.

Many companies offer treatment units to the home market which may reduce concentrations of many trace contaminants. The commercially available treatment units include activated carbon filters, reverse osmosis devices, distillation units, ozonators, ultraviolet purifiers, or combinations of the above. Because no one treatment process can address all water contamination problems, all the types of basic treatments and their effectiveness for the specific contaminant problem must be considered in evaluating the various water treatment units.

A review of existing and potential problems indicated the need to develop basic data and information on the performance of small treatment units with respect to removal of selected organic water contaminants. Subsequently, an evaluation program was developed and has been implemented for the Environmental Protection Agency by Gulf South Research Institute (GSRI) to provide information to governmental officials and the public. The final reporting of this program has four distinct features:

1. The Phase 1 and Phase 2 testing results are briefly covered in the summary of the Results and Conclusions of this report.
2. Phase 3 results with the exception of the surface water spiking studies are reported fully in this report. Specifically, organic and microbiological performance data for typical carbon units have been obtained from the following studies and challenge waters: 1) groundwater study using artesian well water spiked with halogenated organics, 2) home study using New Orleans tap water, and 3) field study using municipal drinking water from four selected cities. Bacterial leaching and gas chromatographic/mass spectrometric (GC/MS) studies were also performed to help evaluate overall performance.
3. A Phase 3 Supplemental Data document provides a tabulation of the raw data used in preparation of this report.

4. Due to problems in the presentation and interpretation of data from the surface water spiking studies such data are separately treated in an "Addendum; Surface Water Spiking Studies - Problems and Interpretation." Study aspects relating to microbiology and distillers have been entirely excluded because of the potential confounding effects of the use of methanol and hexane as organic carrier solvents. However, the Addendum provides data with appropriate qualifications for 10 activated carbon units, two reverse osmosis units, an ozonator, and an ultraviolet/carbon unit.

SECTION 2

SUMMARY OF RESULTS AND CONCLUSIONS

PHASES 1 and 2 - LABORATORY SURVEY STUDY

Phases 1 and 2 were designed to test a wide variety of activated carbon units and one experimental resin unit under laboratory conditions with New Orleans tap water. The thirty-one units were selected to reflect a variety of filter configurations including eight faucet filters (seven bypass and one nonbypass), three potable pour-through filters, five stationary filters, and fifteen line-bypass filters. Eleven units incorporated silver-impregnated activated carbon, and twenty units did not contain silver. In general, the filters contained various amounts of granular activated carbon (16 to 3401 g). They were installed to allow flow rates simulating flow from the home tap, with resulting contact periods of 0.2 to 180 sec.

Organic Compound Removal

THM Removal

Faucet and pour-through filters removed from 4 to 74 percent of the influent THM during the rated lifetime of units. The performance of larger stationary and line-bypass filters ranged from 15 to 99 percent. Six line-bypass units (including one unit containing an experimental material) removed over 85 percent of influent THM. The extent of THM removal appears to be a function of several factors, including quantity of carbon relative to amount of water processed, type of carbon, contact time, and other design features.

NPTOC Removal

Percent removal of nonpurgeable total organic carbon was lower than percent removal of THM for all units except two faucet-mount units. NPTOC removal percentages ranged from 0 to 87 percent for line-bypass units, from 7 to 11 percent for stationary units, and from 6 to 29 percent for pour-through units. Again, as a group the larger filters exhibited higher percentage removals than smaller filters.

Microbiological Parameters

Standard Plate Count (SPC)

The SPC results were divided into three populations: 1) test-unit effluent levels one or more log units less than control-loop levels (population B1); 2) test-unit effluent levels within $\pm$ one log unit of control-loop levels (population B2); and 3) test-unit effluent levels one or more log units greater than control-loop levels (population B3). All units had data

sets greater than control-loop levels (population B3). All units had data sets in population B3, ranging from 13 to 73 percent of total data sets, whereas many units did not have data sets in population B1. In fact, data sets in population B1 ranged only from 0 to 21 percent of total data sets for respective units. The majority of units had their largest portion of data sets in population B2, ranging from 8 to 83 percent of total data sets for respective units. The pattern of data sets for individual units was variable, with reversals from populations B1 to B3 or vice versa occurring between consecutive sampling events. These SPC data indicated moderate and variable effects of activated carbon on bacterial levels in test-unit effluent waters when compared with New Orleans tap water samples under similar conditions (control-loop). In tests for coliform bacteria, none were found in control-loop samples or test-unit effluents.

Endotoxin

The endotoxin results were divided into three populations: 1) test-unit effluent levels less than one-half control-loop levels (population E1); 2) test-unit effluent levels within 1/2 and 2X control-loop levels (population E2); and 3) test-unit effluent levels greater than 2X control-loop levels (population E3). The endotoxin results were of the same nature as SPC results. All test units had data sets in population E3, ranging from 7 to 65 percent of total data sets, while data sets in population E1 ranged from 0 to 40 percent of total data sets. The majority of test units had data sets in population E2 as the largest portion of respective sets, ranging from 20 to 93 percent of total data sets. Rapid shifts or reversals in endotoxin levels were often observed on consecutive sampling periods. Test-unit effluent endotoxin levels were comparable to levels found in 27 different public drinking water supplies utilizing activated carbon treatment (injection of these test waters had failed to demonstrate pyrogenic activity in any of 28 rabbits tested) (1).

Silver Effects

All effluents from silver-impregnated activated carbon units had silver levels less than the Interim Primary Drinking Water maximum contaminant level (MCL) of 50 ppb (average levels from 2-12 ppb). Under test conditions, the data sets for all three categories of SPC bacteria (B1, B2 and B3) and of endotoxin (E1, E2 and E3) were essentially equivalent for silver and non-silver units, showing no significant impact of the silver-impregnation.

Further, statistical methods (student test) also indicated there was no significant difference between the respective SPC populations and endotoxin populations obtained from silver and non-silver units. Thus, it is concluded that silver-impregnated activated carbon units challenged with New Orleans tap water (pH 9.5) did not significantly reduce bacterial growth patterns in their test.

SPC1 versus SPC2

Bacterial plate count values obtained by incubating plates at 35°C for 48 hours (SPC1) have a linear correlation (correlation coefficient = 0.87) with plate counts obtained by incubating plates at room temperature (25°C) for 120 hours (SPC2).

SPC versus Endotoxin

A linear correlation was not observed between $\log_{10}$ of the SPC and endotoxin.

Test-Unit Effluents versus Control-Loop Samples

Out of eight SPC1 and SPC2 statistical analyses, six indicated significantly higher test-unit SPC effluent levels as compared to control-loop levels. Differences between SPC levels varied from 0.20 to 1.09 log units. The data also revealed that increasing degrees of stagnation (from running water to 5-day stagnation) resulted in higher SPC levels for both test-unit effluents and control-loop samples; in fact, SPC bacteria increased more rapidly in control-loop samples than in test-unit effluents. Endotoxin results were less clearcut, with only two out of four statistical analyses showing significantly higher levels in test-unit effluents as compared to control-loop samples. Differences between respective endotoxin levels ranged from 0.7 to 1.4 ng/ml.

Phase 1 and Phase 2 test results have been reported previously (2,3). More detailed data and test procedures are provided in these references.

PHASE 3

Phase 3 elements in this report include: 1) groundwater study; 2) field study; 3) home study; 4) bacterial leaching studies; and 5) spent-carbon study using gas chromatographic/mass spectrometric (GC/MS) analysis. The groundwater study employed spiked challenge water to evaluate severe stress conditions which were not expected to be found under normal home-use; data obtained from these studies may reveal a potential solution to drinking water contamination at various locations throughout the United States.

Groundwater Study

Ten models of activated-carbon home water treatment units were evaluated using well water spiked with 1,1,1-trichloroethane, carbon tetrachloride, trichloroethylene, and tetrachloroethylene at target levels of 50, 20, 50, and 50 $\mu\text{g/l}$ (ppb), respectively. The performance data indicated that the selected models (at least one model from each of the four basic configurations) removed from 76 to 99 percent of the spiked HO in the well water. Generally, carbon tetrachloride and 1,1,1-trichloroethane broke through the carbon filter first while trichloroethylene and tetrachloroethylene did not break through at all for some units. NPTOC and NPCAOX levels in the well water were too low for any observable reduction patterns. Results of SPC indicated slight increases in filter effluent waters (approximately 10X) and the average levels of control-loop and effluent SPC were somewhat higher (but in the same order of magnitude) than corresponding levels observed in the laboratory survey study. These increases in plate count bacterial levels are essentially the same as those experienced in earlier test results from the New Orleans laboratory test. As in the Phase 1 and Phase 2 studies, a correlation between SPC and endotoxin was not observed in the groundwater study. The silver units again demonstrated no measurable bacteriostatic effects on plate count bacteria.

Field Study

Four activated-carbon units were evaluated using the drinking water in four United States cities: Miami, Florida; Atlanta, Georgia; Pico Rivera, California; and Detroit, Michigan. This was done as a cursory attempt to define the applicability of using laboratory generated performance data (from New Orleans) test to predict test unit performance when challenged by waters of other source and quality. The following general statements can be made after studying the experimental data from the field test study.

It appears upon reviewing the THM reduction data, that the relative unit performance ranking determined in laboratory test is maintained throughout the field study. The second observation to be made is that the overall level of specific organic chemical removal appears to be adversely affected by increased levels of background organic material present in the water matrix. This effect is not as pronounced as the first observation, but does seem to be indicated. Unfortunately, no quantitative estimates could be made with respect to the average removal levels due to the limited data base and the experimental error involved in some of the low level THM measurements.

To the extent determinable from the data, the type source water did not significantly affect the removal capabilities of NPTOC. The average levels of NPTOC were different for each source water but the percent reductions were comparable to those experienced in laboratory test.

The bacterial aspects, standard plate count (SPC), and endotoxin of the field study experiments revealed few differences from the laboratory test results. Increases in average SPC levels were observed for both the silverized carbon as well as the non-silverized units. Fewer increase/decrease reversals were observed in the field study with effluent SPC levels ranging from 1-30,000/ml and influent SPC levels between 1-1,800/ml. Average influent to effluent increases were comparable to those observed in laboratory tests. Due to a limited data base and scatter in existing data, a statistical breakdown of the effects of various source waters, carbon filter units, SPC and endotoxin was not feasible.

Two primary conclusions can be drawn from the field study data. Filter unit percent removals of THM compounds can be predicted with some confidence using results based on laboratory test. The total organic background level, NPTOC, in water may affect percent reduction levels of THMs slightly (approximately 10-20 percent) over the range of background organic levels experienced in the field study (0.6 to 7.1 ppm NPTOC). The ranking of filter units appears to be maintained regardless of the source water. The ranking could change if one was monitoring the filters effectiveness in removing a different contaminant since many carbon adsorbents are manufactured with some degree of selectiveness. Our experience has been that this occurs infrequently and one can be fairly certain that units demonstrating effective removals of THM compounds will also demonstrate strong affinities to most other halogenated organic compounds.

The second conclusion to be drawn from the field studies pertains to the bacterial aspects of the filters. Indigenous bacteria as enumerated by the SPC method can be expected to increase slightly in water processed by the filter. The increases experienced in field testing appear comparable to those demonstrated in the laboratory test.

The agreement of field test with laboratory test was generally good. Laboratory test data should serve well in estimating filter unit performance for organic removal in almost any drinking water source. Extrapolation of laboratory test results on one chemical compound to another compound should be executed with caution, since there are known classes of compounds for which carbon has very little affinity (e.g. alcohols).

Home Study

Three filter types of activated-carbon units were challenged with New Orleans tap water under both accelerated (Phase 1 laboratory test) and nonaccelerated (three homes) experimental conditions in an effort to determine the validity of accelerated laboratory testing. The respective individual data sets describing THM reduction for two of the three units were essentially the same in both home and laboratory tests. THM reduction data for one of the three demonstrated lower levels of removal than in the corresponding laboratory test. This result has not completely been explained. The correlation of THM reduction appeared to be valid even though the average rate of test acceleration was 19X and 76X for the two units. Test flow rates and average challenge THM levels were different in the home and laboratory tests; however, these two factors did not appear to significantly affect ($\pm 10\%$) THM reduction capabilities of carbon units that were operated with short contact times (~ 1 min or less) between the challenge water and activated carbon. NPTOC data sets from the respective units tested in the home study were similar (both in magnitude and pattern) to the respective data sets in the Phase 1 laboratory study. No significant differences between laboratory and home (actual use) test conditions were revealed by either SPC or endotoxin data.

Limited data from the home studies indicate the validity of using accelerated laboratory testing to provide an accurate assessment of the effectiveness of carbon filtration in removing trace organic chemical contaminants from drinking water. Organic chemical removals and bacterial aspects of the home test were generally comparable to those obtained for laboratory test. A larger data base would be required to assure the positive correlation between laboratory (accelerated) test and home (actual use) test although preliminary data indicate the laboratory test provide valid assessment data.

Bacterial Leaching Studies

The bacterial leaching and flushing studies were designed to attempt to characterize the initial bacterial flushing from three types of water dispensing fixtures (faucet with aerator, faucet without aerator, and spray

attachment) and four different types of activated carbon filters. This study element was the first attempt to evaluate the filter unit effluent SPC levels as a function of time (flushing). Results of the unit flushing study support the assumption of "first water" representing worst case bacterial situations. Statistical examination of the data indicated the "first waters" exhibited higher SPC levels than subsequent flush waters (at an 80 percent confidence level). This has been the assumption made throughout the study and is the basis for routinely collecting bacterial samples as "first water" samples.

Monitoring the time or flush volume dependence of SPC levels enables one to observe secondary effects which may have been occurring in filters. An example of one secondary effect observed appears to be the apparent low levels of SPC bacteria in the Concept filter effluent water after a short initial flush time. This was probably due to design feature of this particular filter. These type characteristics of the filters have not been evaluated routinely and would normally not be observed with studies focusing on "first water" samples.

Two observations were drawn from the faucet flushing experiments. Examination of first flush waters from the faucets indicate no significant difference between the three type water fixtures. The data was challenged with the student "t" test at both 90 percent and 80 percent confidence levels. The difference in SPC levels for the first 0.25 gallon of each fixture's flush water was not significant at either confidence level.

Another notable observation from the faucet flushing study was the variability of the bacterial quality of the source water. This variability, in some situations, is larger than the responses being monitored. The problem of "control" water SPC variability has been present throughout the study and often complicates data interpretation. The problem of SPC level variability, the limited scope of the flushing studies, and the level of data scatter prevent other meaningful conclusions from being drawn.

Spent Carbon Study

Activated-carbon from three types of home water treatment units (line bypass, stationary, and faucet-mount) was analyzed after the respective units had been tested in the surface water study. The three extracts were similar and contained a complex mixture representing the following classes of compounds: 1) biologically-derived acids, esters, alcohols; 2) halogen-containing compounds; 3) common solvents such as phenol, glycol, ethers, alcohols, and ketones; 4) phthalates; and 5) hydrocarbons, alkanes, and alkenes. The compounds identified were those primarily present in the challenge water and those expected to be adsorbed most strongly by activated-carbon.

SECTION 3

EXPERIMENTAL PROCEDURES

TEST PROTOCOLS

Overview of Phase 3 Experiments

The following studies were completed during Phase 3: 1) groundwater study using activated-carbon units, 2) four city field tests of activated-carbon units, 3) three home tests in New Orleans of activated-carbon units, 4) bacteriological leaching studies of activated-carbon units and kitchen faucets, and 5) study of spent activated-carbon from units using gas chromatographic/mass spectroscopic (GC/MS) analyses.

Generally, each study involved the testing of home treatment units challenged with different types or sources of water. The procedures and parameters were designed to yield accurate, reliable data to evaluate how effectively the units reduced or removed selected and spiked halogenated organics (including trihalomethanes and pesticides), nonpurgeable total organic carbon, and total organic halide. In addition, the studies included important information concerning the bacterial and endotoxin content of the home water treatment units throughout each test. The experimental protocols were developed by incorporating input from EPA, unit manufacturers, and industrial users.

Performance Testing/Sampling Schedule

Although each Phase 3 study had different objectives and test procedures, each study contained many test protocols and performance parameters that were identical to those in earlier studies. The following descriptions of the testing manifold, test procedures, and sampling schedule were applicable to most of the studies. Any deviation from these test protocols and performance parameters for each Phase 3 study is explained in the appropriate subsection in the Results and Discussion section of this report.

Each unit was installed on the test manifold and plumbed according to the manufacturer's recommendations. Suggested startup procedures were completed before initiation of each run. The flow rate of most units was not regulated except by restrictions in the filter device and associated hardware, primarily the faucet and line-tapping valves. The test manifold was designed with oversized tubing so that the manifold itself did not restrict flow. Test flow rates were determined by evaluating the flow through the plumbing train (including an appropriate faucet and tapping valves) with the

manifold's orifice monitor/controller fully open. Pressure was held constant at 40 psi. The faucet and other nonessential hardware was then removed from the plumbing train and the unit installed. If the flow rate exceeded that originally allowed by the manufacturer-supplied hardware, the controller was set to the flow rate determined in the original 40 psi test. Through this initial adjustment, the normal maximum flow rate was applied to each model during each run. The same procedure was followed for all units operating in the pressurized mode. Flow through the pour-through models was set to the manufacturer's recommended values by adjustment of the orifice.

The schedule for sampling events and run duration was based on individual unit capacity and flow rate. For units where flow rate and capacity (gallage) were not available, values of similar units with equivalent amounts of carbon were employed. This procedure was used to establish the total number of gallons to be processed by each unit per day. Sampling events were scheduled at or near predetermined gallage values for each model. Figure 1 depicts a general usage profile showing the main sampling events. Samples were taken at least five times during the life of the test units. These five events corresponded to approximately 0, 25, 50, 75, and 100 percent of the unit life expectancy.

A typical 24-hr day sampling schedule is depicted in Figure 2. Each day included an 8-hr stagnation to stimulate overnight nonusage time. The units were then intermittently run for 16 hr, held stagnant for 8 hr, and the cycle repeated. Most samples for bacterial/endotoxin assay were collected immediately after the overnight stagnation periods (i.e., "first water" samples). The spiked halogenated organics, THM, NPTOC, TOX, silver, and chlorine samples were collected approximately 6 hr after the start of the test day and 1 min after the downstream holdup volume of the unit had been wasted. This collection procedure ensured collection of a dynamic sample rather than a sample which had extended contact time with the adsorbent material. Influent or control-loop effluent and test-unit effluent water samples were collected for comparison and analysis of the various performance parameters.

During the experimental runs on each model, the target duty cycle was no more than 10 percent "on" for each hour during the 16-hr working day. Therefore, for each of the 16 hr of manifold operation each day, the running time was limited to approximately 6 min per hourly cycle, or 96 min a day (i.e., $96 \text{ min/day} \times 0.8 \text{ gal/min} = 76.8 \text{ gal/day}$). The expanded list of performance parameters in Figure 1 was monitored during the test. In addition to the "first water" samples collected for SPC and endotoxin analysis, several "running water" samples were collected and analyzed.

The units were run until the manufacturer's rated gallage had been processed or until the unit failed by premature plugging. While early protocols included a chemical failure option for test run termination (10 percent or less removal), this criterion was rarely implemented. A

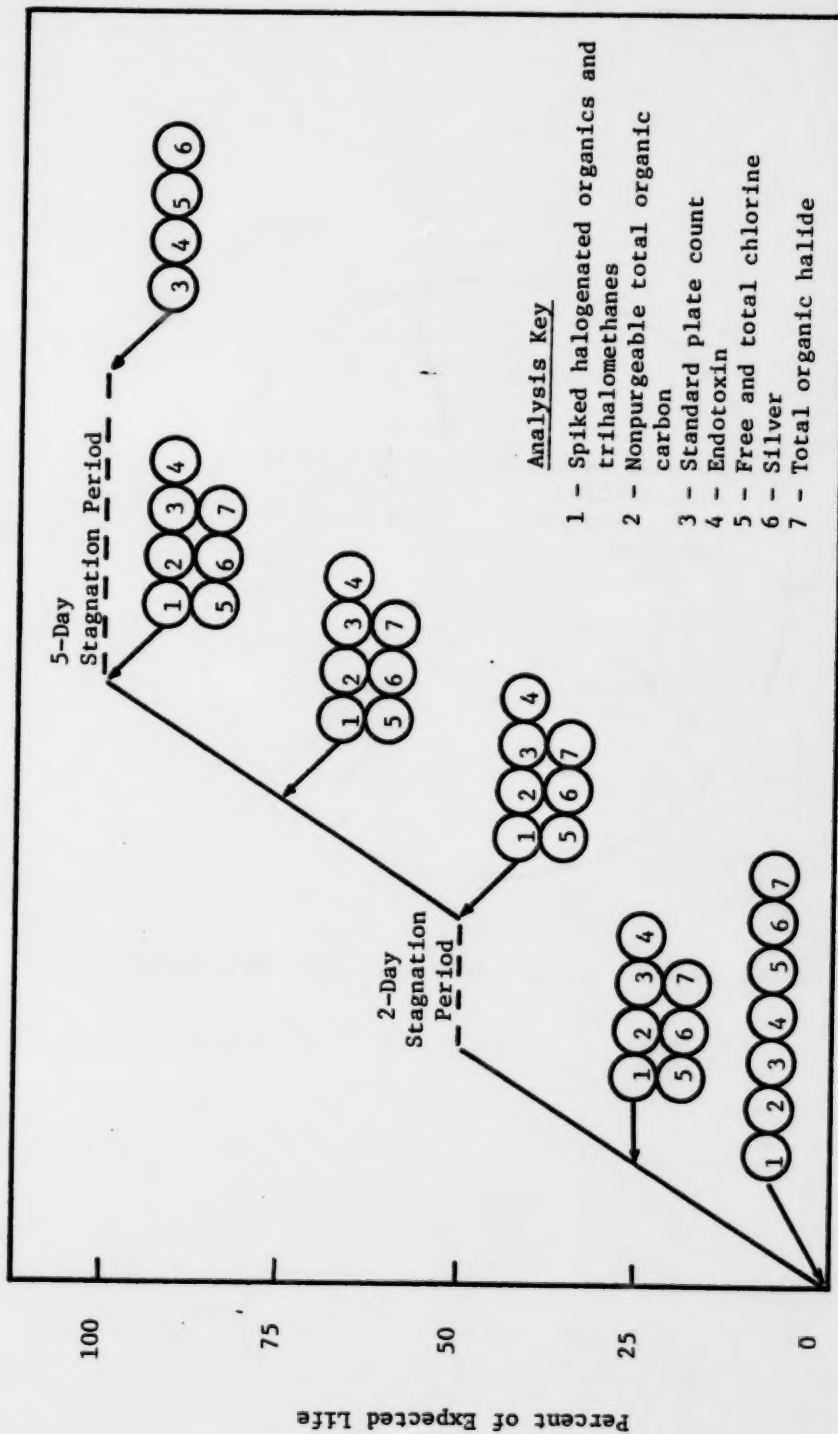


Figure 1. General usage profile indicating target sampling events.

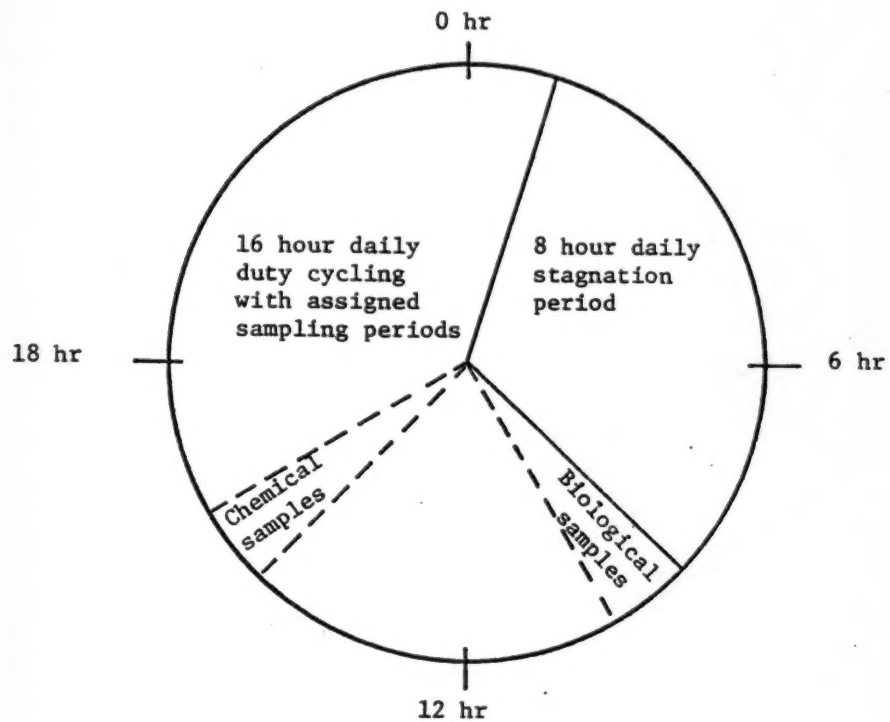


Figure 2. Routine daily schedule for all test models.

bacterial sample was collected five days after the termination of a run in an attempt to determine how extended dormancy affected effluent water quality. When the second and third trial runs were completed, the flow through the units was stopped, and the units were held under line pressure (if this step was applicable) for five days; then, the units were turned on long enough to collect the last SPC/ endotoxin samples.

WATER-SPIKING-SYSTEM

An integral part of the groundwater study was the development and employment of a dependable water spiking system. Figure 3 depicts the water spiking system and the following is a description of how the overall spiking system worked. The matrix water was drawn from the groundwater source (artesian well) at point (A). The water was prefiltered (B) to remove sediment and pumped (C) into an 80-gallon glass-lined tank (F). A concentrate (J) of the "spike" compounds was added (K) to the feed water by injection, and mixing was achieved by an in-line static mixer (E). The volume of water in the supply tank (F) was maintained at three fourths full by controlling the supply pump (C) and the metering pumps (K) with a level controller (L) in the supply tank. The pressure above the water in the supply tank (F) was maintained by compressed nitrogen (G). Operating the supply tank under pressure helps to minimize losses of volatile organics into head space areas. Another feature of the spiking system designed to produce a consistent "spike" was the manner in which the spike concentrate (J) was metered into the supply tank (F) via the static mixer (E). Initially, the supply pump (C) and the metering pumps (K) were activated when the level controller (L) indicated that the level of water in the supply tank was less than three fourths full. Next, to correct for variations in the start-up flow rates of each pump, the first volumes of water and concentrate (produced by 30 seconds of pump operation) were discarded. Only after 30 seconds of run time did the blend enter the supply tank.

The various filter units in the groundwater studies were tested with water from the supply tank while on/off cycles of challenge water to individual units were regulated by a timer cam control system similar to what was used and reported in the laboratory tests of these units during Phase 1 (5/10/79) and Phase 2 (6/30/80).

METHOD OF ANALYSIS

Selected Chlorinated Hydrocarbon

Sampling--

Crimp-top serum bottles with Teflon-lined septa were used to collect the HO samples. Prior to sampling, the bottles were cleaned using the following procedure:

- Wash in a hot soap and water solution
- Rinse in tap water
- Rinse in Chromerge

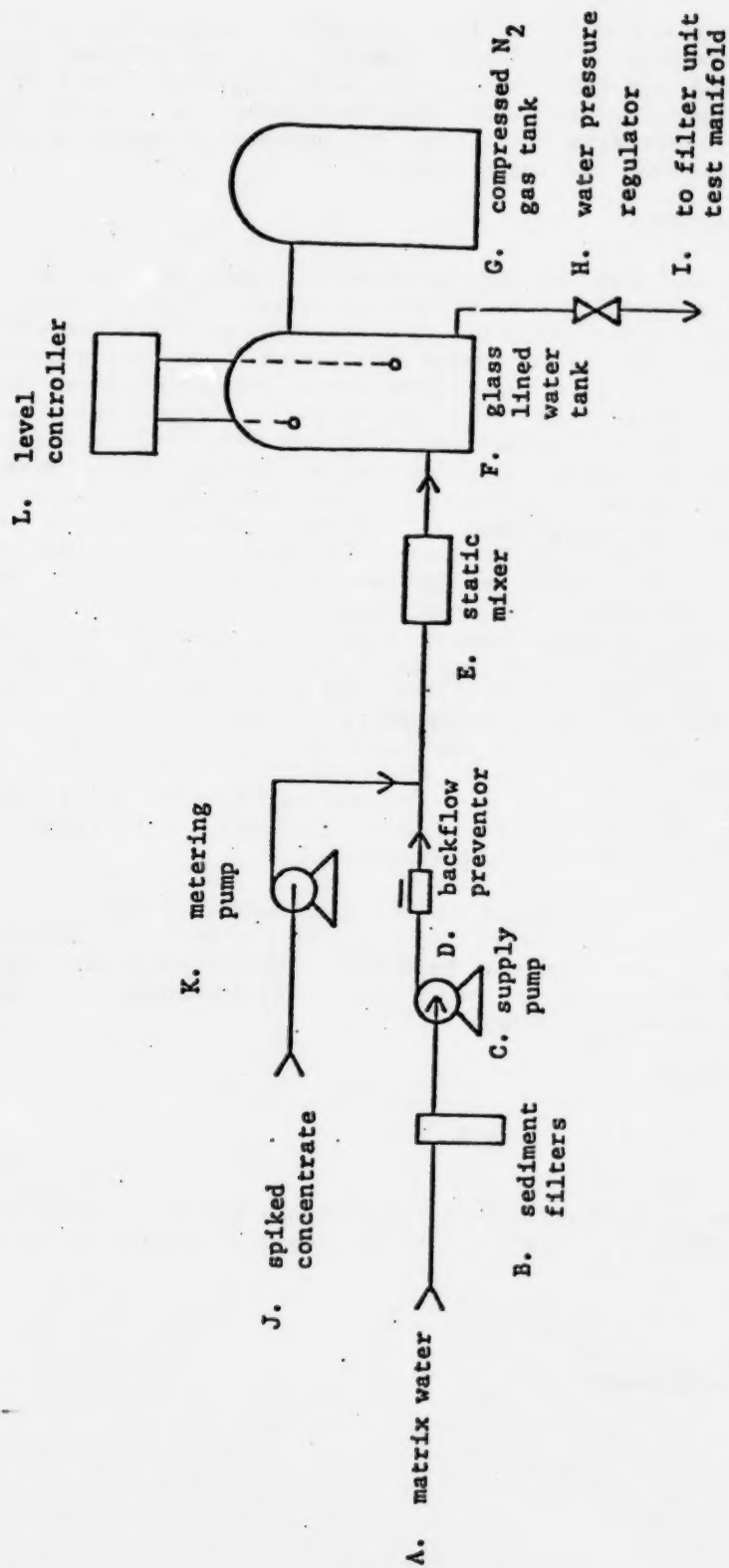


Figure 3. Water spiking system.

- Rinse thoroughly in deionized water
- Rinse thoroughly in distilled water
- Rinse in methanol
- Drain dry
- Heat at 400°C for at least 1 hr
- Cool to room temperature
- Add 1 ml of 0.25 percent sodium sulfite per 100 ml sample
- Cap using Teflon-lined septum and crimp top, making sure the Teflon lining faces the sample.

When samples were collected, the crimp top was removed and the bottle filled to overflowing. Care was taken in resealing the sample bottle to avoid inclusion of air which could result in the loss of volatile organic compounds. The sodium sulfite solution added to each sample is generally accepted as adequate to quench the haloform reaction which results from the chlorination of drinking water. Samples were refrigerated at 4°C until analyzed.

Analysis--

The analysis of water samples for spiked halogenated organics and trihalomethanes was performed using liquid-liquid extraction techniques followed by separation and quantification of the compounds of interest by gas chromatography (GC) with a ⁶³Ni electron-capture detector (4-6). Table 1 describes both sets of gas chromatographic conditions employed during Phase 3 test.

In the groundwater study, 1,1,1-trichloroethane, carbon tetrachloride, trichloroethylene, and tetrachloroethylene were analyzed using reagent-grade methylcyclohexane (MCH) as the extraction solvent. The MCH was purified by distillation and, if necessary, by passing it through a basic alumina column. A 5-ml aliquot of influent or 10-ml aliquot of effluent sample was extracted by shaking with 1 ml of purified MCH. The layers were allowed to separate, and a 3-μl portion of the organic layer was injected into the GC. Chromatographic conditions and a typical GC trace for this analysis are listed in Table 1, Method 1 and shown in Figure 4. Qualitative identification was based on matching the retention times of peaks in the sample chromatogram with those in the chromatogram of a standard mixture containing the four compounds of interest. Confirmation of compound identity (no interfering compounds were observed in the ground or surface water samples) was possible by reanalyzing any sample in question under different conditions of liquid phase, solid support, temperature, and flow rate (Table 1, Method 2). The quantification technique employed was external-standard method, and all calculations were based on integrated peak areas, peak heights, or both.

Nonpurgeable Total Organic Carbon Analysis (NPTOC)

Sampling--

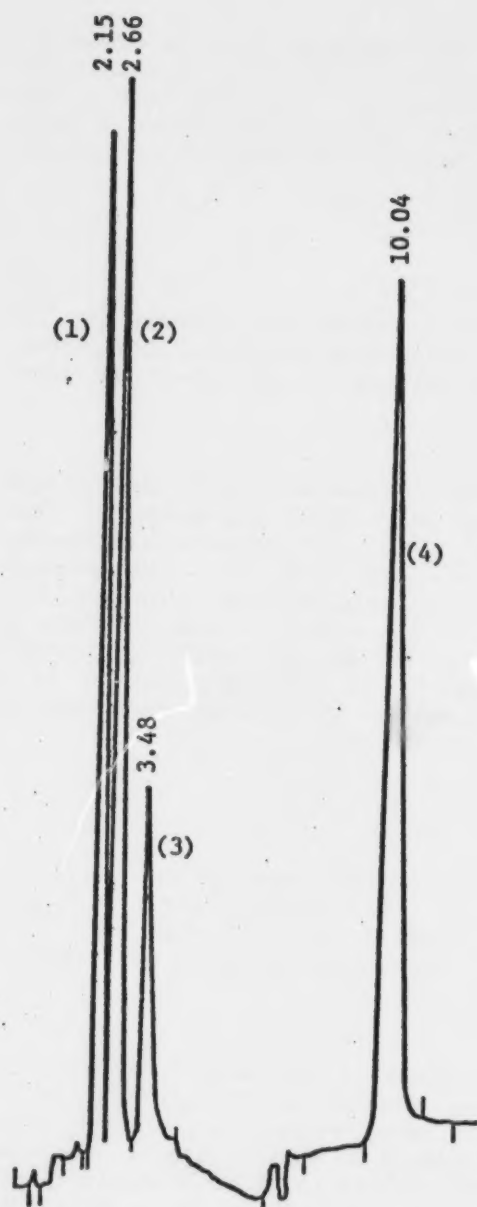
Cleaning and sampling techniques used in collecting samples for NPTOC analysis were identical to those used in the spiked halogenated organics and THM analysis procedure.

TABLE 1. EXPERIMENTAL CONDITIONS FOR SPIKED HALOGENATED ORGANICS AND TRIHALOMETHANE ANALYSIS

Parameter	Method 1	Method 2
Column	A	B
Injection temperature	150°C	150°C
Oven temperature	67°C	80°C
Temperature program	isothermal	isothermal
EC detector temperature	300°C	300°C
Flow rate	20 ml/min	30 ml/min
Injection volume	3 μ l	3 μ l

Column A: 6 feet x 1/8 inch I.D. glass column packed with 10% Squalane on 80/100 mesh AW Chromosorb W.

Column B: 6 feet x 1/8 inch I.D. glass column packed with GP2100/0.1% Carbowax 1500 on 100/200 mesh Supelcoport.



Peak	Compound	Concentration (ppb)
1	1,1,1-trichloroethane	53.6
2	carbon tetrachloride	19.1
3	trichloroethylene	52.6
4	tetrachloroethylene	51.8

Gas chromatographic conditions, Method 1: 6 ft x 1/8 inch I.D. glass column packed with 10% Squalane on 80/100 mesh AW chromasorb W; carrier gas 5% methane, 95% argon; flow rate 20 ml/min; injector temperature 150°C; column temperature 67°C (isothermal); Ni⁶³ electron capture detector temperature 300°C.

Figure 4. Representative chromatogram of a spiked halogenated organics check standard.

Analysis--

NPTOC analyses were performed using the Dohrmann Model 54 analyzer. Using the procedure outlined by the manufacturer (7), 10 ml of sample was presented to the instrument, acidified, purged for inorganic carbon, and oxidized using an ultraviolet light catalyzed system. The carbon dioxide produced was converted to methane, and the methane was detected and quantified using a flame-ionization detector.

Total Organic Halide Analyses (TOX)*

Sampling--

Cleaning and sampling techniques used in collecting samples for TOX analyses were similar to those used in the preceeding analytical procedures. However, instead of crimp-top vials, 500-ml bottles fitted with Teflon-lined screw caps were used.

Analysis--

The total organic halogen (TOX or TOHa) analyses were performed using a Dohrmann instrument similar to the Dohrmann Model DX-20 TOX analyzer. This instrument analyzed for both purgeable (POX) and nonpurgeable carbon adsorbable organic halide (NPCAOX) which together equal TOX. The Dohrmann TOX method consisted of two steps. First, organics were adsorbed onto granular activated carbon (GAC), and the GAC was washed to remove traces of inorganic halides. Second, the GAC was pyrolyzed, and the resulting hydrogen halides were determined by microcoulometry.** To calculate the TOX of a sample, the sum of the halides derived from two GAC columns (connected in series) was divided by the volume of water processed.

Inorganic Analyses (Silver)

Sampling--

Glass bottles were washed in hot water and detergent, rinsed with tap and deionized water, cleaned with 1:1 nitric acid:water, rinsed thoroughly with deionized water, and drained dry. Samples for silver analysis were preserved upon collection with nitric acid (to lower the pH to less than 2) and stored at 4°C.

Analysis--

Influent and effluent samples were prepared for silver analysis by digesting 200 ml of sample with 3 ml of concentrated nitric acid and 5 ml of 30 percent hydrogen peroxide. The samples were covered with a watch glass and heated at 95°C until the volume was reduced by evaporation to less than 50 ml. The digested sample was cooled and diluted to 50 ml with distilled, deionized water. The digested, concentrated samples were analyzed for silver

*All TOX analyses were performed by the University of Missouri, Columbia, Missouri.

**Manufacturer's instruction manual, Dohrmann Envirotech, 3240 Scott Boulevard, Santa Clara, California 95050.

using an Instrument Laboratories (IL) 551 atomic absorption spectrophotometer (AAS) equipped with a heated graphite atomizer (IL 555) deuterium background correction and a graphics display. A series of standards was prepared and analyzed with each set of samples. The height of the absorbance peak of each standard was measured and correlated with the respective concentration to produce a calibration plot. Silver was quantified by comparison of sample absorbance peak height with the standard calibration plot.

Arsenic, barium, cadmium, chromium, lead, and selenium were determined in a similar manner on New Orleans tap water by flameless atomic absorption using an IL 551 equipped with an IL 555, deuterium background correction, and a graphics display. Samples were prepared for analysis by digesting 100 ml of sample with 3 ml concentrated nitric acid and 5 ml 30 percent hydrogen peroxide (8). The following inorganic parameters were determined by using techniques cited in the Manual of Methods for Chemical Analysis of Water and Wastewater (9). Fluoride was measured using an Orion ion activity electrode. The cadmium-reduction method was used to determine nitrate nitrogen. Total dissolved residue was determined gravimetrically. A nephelometer was used for determination of turbidity. Conductivity and pH were determined with a YSI conductivity bridge and an Orion digital pH meter.

Chlorine Analysis

Sampling--

Samples for chlorine analysis were collected in clean 250-ml Ehrlenmeyer flasks with glass stoppers and titrated within 60 min.

Analysis--

Concentrations of free and residual chlorine in influent and effluent water samples were determined using a titrimetric method (10). Free chlorine was determined by transferring 100 ml of sample, 5 ml of phosphate buffer, and 5 ml of DPD indicator (N,N-diethyl-P-phenylenediamine) to a 250-ml flask and titrating immediately with a standard FAS titrant (ferrous ammonium sulfate) until the red solution became colorless. Residual chlorine was determined by adding ≈ 1 g of KI to 100 ml of sample, waiting 2 min for complete color formation, and titrating as for free chlorine. Because of relatively low concentrations found for free and residual chlorine, the standard FAS titrant (1 ml FAS = 1 ml/l chlorine) was diluted 1:10 for increased accuracy.

Microbiological Analysis

Sampling--

All sample bottles and glassware used for microbiological analyses were washed with detergent and hot water, rinsed with hot tap water, and thoroughly rinsed with distilled water. The glassware was sterilized by heating at 170°C for 60 min. A sterile-filtered solution of 7.3 percent sodium thiosulfate and 5 percent sodium thioglycolate was added to each sample upon collection at the rate of 1 ml per 100 ml sample. The thiosulfate and thioglycolate neutralize any chlorine or silver present in the sample and

thereby prevent bacterial kill after sample collection. Samples were cooled to 4°C immediately and stored until analysis. Standard plate count determinations were performed according to standard procedures (11).

Analysis--

Standard Plate Count--A standard plate count was performed within 30 hr of sample collection according to standard procedures (11). Dehydrated agar was reconstituted and sterilized according to the manufacturer's instructions. The agar was melted and tempered in a 44-46°C water bath. Each water sample was diluted with sterile water and plated in triplicate at the following concentrations: influent 10^0 , 10^{-1} , 10^{-2} and effluent 10^{-1} , 10^{-2} , 10^{-3} . The plates at each concentration were incubated at $35 \pm 0.5^\circ\text{C}$ for 48 ± 3 hr. The colonies growing on each plate were counted using a Quebec colony counter. All samples were analyzed in triplicate.

Endotoxin Assay--The endotoxin assay was conducted using the Worthington Limulus amoebocyte lysate (LAL) Pyrostat test kit, a turbidimetric modification of the Limulus amoebocyte lysate gel test for detecting pyrogen (1, 12-14). Each sample was diluted 1:10 and 1:25 to insure that the endotoxin concentration of the sample fell within the range of the standard curve. A 0.1 ml aliquot of diluted sample or reference endotoxin standard was added to a chilled test tube containing 1.0 ml LAL reagent. The contents of the tube were thoroughly but gently mixed, and the tube was placed into a 37°C water bath to incubate for 60 ± 1 min. The contents of the tube were transferred to a cuvette, and the optical density measured with a Varian Techtron UV-Vis spectrometer. A four-point standard curve was constructed by using the concentration and optical density of the reference endotoxin standards. The optical density of each sample was compared to the standard curve to determine concentration of endotoxin in the sample.

Gas Chromatographic/Mass Spectrometric Analyses (GC/MS)

Sampling--

All sample bottles and glassware used in the GC/MS analyses of spent activated-carbon were washed with Chromerge, rinsed with tap water, rinsed with methanol, and dried in an oven at 120°C. The volatile samples (purge-and-trap analyses) were collected into a 40-ml vial with no headspace and stored at 4°C. The semivolatile samples (Soxhlet and liquid/liquid extraction) were extracted and then stored at 4°C in 2-ml sample vials.

Analysis--

The spent activated-carbon from home treatment units was analyzed for both volatile and semivolatile compounds. In addition, a 50-gallon sample of New Orleans tap water was serially extracted and analyzed to provide a reference sample containing compounds that are reduced or removed by the activated-carbon units. The adsorbed volatile compounds were identified by purging 10 g of the used activated-carbon in 40 ml of water heated to 30°C and trapping the organic compounds on a Tenax trap. The trap was thermally desorbed at 200°C, and the compounds collected at the head of the GC column at -30°C. The GC column was temperature programmed and the eluting organic

compounds were identified by mass spectral analysis. The adsorbed semi-volatile compounds were identified by Soxhlet extracting 50 g of the used activated-carbon with methanol for 18 hr. The methanol extract was concentrated to 10 ml using K-D evaporators. The 10 ml extracts, which contained large amounts of H_2O , were extracted with CH_2Cl_2 , dried with Na_2SO_4 , and concentrated to 1 ml. A 2 μ l aliquot of the extract was analyzed by the GC/MS system.

The 50-gallon sample of New Orleans tap water serially extracted with 1 gallon of CH_2Cl_2 (3X) and the organic layer concentrated to 2 ml. A 2 μ l aliquot of the organic extract was analyzed by the GC/MS system. The operating conditions for the respective GC/MS analyses are listed in Table 2.

QUALITY ASSURANCE/QUALITY CONTROL PROTOCOLS

Spiked Halogenated Organics and THM Analysis

A rigorous quality-control program was followed in conjunction with these analyses. Before Phase 1 of this program, a nine-point calibration curve was constructed for each THM compound to establish detection limits and linearity ranges. Performance samples of THM were supplied to GSRI by the Environmental Monitoring and Support Laboratory of EPA for verification of the analytical procedure. A satisfactory rating was received. During Phase 3, GSRI established seven-point calibration curves, detection limits, and linearity ranges for the additional spiked halogenated organics: 1,1,1-trichloroethane, carbon tetrachloride, trichloroethylene, and tetrachloroethylene. Performance samples of the spiked compounds were again supplied to GSRI by EPA. A satisfactory rating was received. The following quality-control samples were run each time the samples were analyzed during Phase 3:

- solvent blank: aliquot of solvent which was used to extract that day's samples.
- method blank: extract of water which was used to prepare standard.
- low standard: standard in which the concentration of each compound was higher than at the midpoint of the calibration curve.
- check standard: standard in which the concentration of each compound was approximately the concentration expected in the samples.
- duplicates: extracts from two samples collected sequentially from the same sampling point.
- spikes: extracts from two samples collected sequentially from the same sampling point. One of these samples was fortified with a mixture of the compounds of interest at known concentrations.

Analysis of extracting solvent and method blanks provided a check on the purity of the materials used in the procedure. If any amount of the five halomethane compounds was detected in these samples, that material, either solvent or water, was purified again and reanalyzed before it was used. Analysis of the low, high, and check standards monitored the performance of the GC on a day-to-day basis. If values obtained from analysis of these

TABLE 2. GAS CHROMATOGRAPHIC/MASS SPECTROMETRIC CONDITIONS FOR SPENT ACTIVATED-CARBON ANALYSIS

Parameter	Gas Chromatographic	
	Volatile Organic Compounds	Base-Neutral and Acid Semivolatle Organic Compounds
Carrier Gas	UHP Helium	UHP Helium
Carrier Flow	20 ml/min	2.0 ml/min
Injection Temperature	225° C	260° C
Column	0.1% SP-1000 on Carbowack C 6 foot x 2 mm i.d.	30 m x 0.25 mm ID glass capillary column WCOT coated with SE-54
Temperature Program	30° C to 220° C at 8°/min	30° C (1 min) to 260° C at 6°/min
Mass Spectrometric		
Instrument	HP 5982A GC/MS	HP 5993A GC/MS
Scan Start Delay	0 min	5 min
Mass Range	20-360 amu	35-450 amu
Dwell Time	168 amu/sec	315 amu/sec
Electron Multiplier Voltage/Detector Gain	2200 volts/=10 ⁴ gain	2200 volts/=10 ⁴ gain
Ion Source Temperature	150° C	200° C

quality-control samples ranged outside the limits of precision, the nine-point calibration curve was reconstructed and a thorough check of the instrument parameters, column conditions, and detector response was made.

The precision of the procedure was established by the analysis of duplicates. Precision was quantified according to the equation

$$R_c = 3.27C \frac{\sum R_i}{\sum X_i} \quad (1)$$

where

R_c = critical difference
 X_i = average value obtained for duplicate analyses
 R_i = difference between the values obtained for duplicate analyses.

Qualitatively, the smaller the R_c value, the better the precision of the analysis. Quality-control charts were generated from these data and updated each day the analyses were performed.

Accuracy of the analyses was monitored by comparing the value obtained for the check standard (O_i) with the true value (T_i).

$$P_i = 100(O_i - X_i)/T_i \quad (2)$$

where

P_i = percent recovery (accuracy)
 O_i = observed value
 T_i = true value
 X_i = dilution factor (if significant)

The recovery efficiency of the analysis was determined by analyzing spiked samples and comparing the difference in the values obtained for the spiked and unspiked samples with the level at which the sample was spiked (essentially Equation 2). If the halomethane concentration in the sample was expected to fall in the lower half of the calibration curve, the sample was spiked at a level approximately equal to the concentration of the compounds already present. If the sample concentration was anticipated to be above that of the midway point of the calibration curve, the spike was approximately half of the value expected in the sample.

NPTOC Analysis

The quality-control program associated with the NPTOC analyses was similar to that described for CCl_4 and THM analyses. Because the method of analysis for NPTOC is routinely reliable, a reduced schedule for the analysis of QA/QC samples was employed as follows:

Monday - water blank, method blank, low standard, high standard, check standard, duplicates, and spikes.

Tuesday and Thursday - water blank, method blank, low standard, check standard, and duplicates.

Wednesday and Friday - water blank, method blank, high standard, check standard, and spikes.

TOX Analysis

The quality-control program associated with the TOX analysis (TOX = POX + NPCAOX) consisted of daily method recovery samples, spikes, and duplicate samples. Chloroform was chosen to represent a typical POX compound and trichlorophenol to represent a typical NPCAOX compound. The recovery of each compound (method recovery) was determined each day samples were analyzed. Duplicate sample analyses were performed periodically (~ every 15 samples) and various spiked samples were analyzed to confirm the accuracy of the TOX method.

Silver Analysis

The quality-control program for silver analysis was conducted concurrently with individual silver analyses. QA/QC samples representing 10 percent of the total number of samples for silver analysis were analyzed. These QA/QC samples included duplicate samples, spiked samples, and quality-control standards.

Microbiological Analysis

Sterility of medium, dilution water, glassware, and membrane filters was verified by preparing blank control plates with each set of samples examined by the SPC or LAL (endotoxin) procedures. Standard plate counts were plated in triplicate, and endotoxin determinations were calculated at two dilutions.

SECTION 4

RESULTS AND DISCUSSION

GENERAL OBSERVATIONS

Test Water Quality

The experimental program elements of Phase 3 were designed to simulate variable stress conditions for the testing of home water treatment units. Since the adsorption of an organic chemical on activated-carbon is dependent on a variety of physical characteristics (including polarity, molecular size, water solubility, concentration of the compound in water, and pH of source water), the crucial experimental variable in Phase 3 experiments was the quality of challenge water (spiked or unspiked). Consequently, specific aspects of the respective challenge waters were monitored to assess their effects on the performance of various types of home water treatment units.

Tap water drawn from the New Orleans municipal supply was employed as the basic challenge water in the home study and the bacterial leaching study. There are several features of this tap water which may distinguish it from some other sources. The Mississippi River is the raw water source for which classical treatments of permanganate oxidation (as needed), flocculation, lime softening, and disinfection at the water-treatment plant was employed. The pH of the treated water was basic; typical values ranged between 9 and 10. Total nonpurgeable organic carbon concentrations were not exceptionally high (range was between 1.7 and 3.5 ppm); however, the mixture of organic compounds which comprised this total may be one of the most complex groups of chemicals found in domestic drinking water supplies. The Mississippi River contains pollutants from all surface water drained from the mid-continental United States. This water contains humic, agricultural, and other wastes. Several cities dispose of sewage waste through the Mississippi River, and the river has a large number of chemical and petrochemical industries along its banks.

In the groundwater study, an artesian well near Bay St. Louis, Mississippi was chosen to represent an untreated and uncontaminated groundwater source. In the field study, municipal drinking water from Miami, Florida; Pico Rivera, California; Detroit, Michigan; and Atlanta, Georgia were used as challenge waters.

Supplemental data Table S1 reports the daily influent water concentration of spiked halogenated organics present during the groundwater study. Supplemental Table S2 reports the microbiological levels of the groundwater

as measured at the control loop. Supplemental Table S3 summarizes the water quality of New Orleans tap water and the artesian well water using most of the parameters defined in the Primary Drinking Water Standards and the proposed Secondary Drinking Water Standards. The above tables are found in Phase 3 Supplemental Data document accompanying this report.

Physical Description of Home Treatment Units

An important objective of Phase 3 experiments was the evaluation of the performance of both activated-carbon and noncarbon home water treatment units. The following descriptions report some of the important and comparable features of the various units tested.

Activated-Carbon Units

A physical description of the 12 activated-carbon units tested during Phase 3 is presented in Table 3. Four types of units were tested: 1) line-bypass, 2) faucet-mount, 3) stationary, and 4) pour-through. Each unit had a rated capacity (gallons/liters) provided by the manufacturer or estimated. Estimated capacities were determined by comparison of the amount of activated carbon in similar units. Capacity ratings, which are dependent on amount and type of carbon, ranged from 200 to 4000 gal. The iodine number (indicative of the type of carbon), amount of activated carbon, test flow rates, and design features are factors which determine the adsorption capacity of each unit. All units tested have short empty bed contact times; the longest is 3 min. This empty bed contact time differs significantly from the 5- to 30-min contact times used in water-treatment plants (15).

GROUNDWATER STUDY

Overview of Groundwater Study

In the groundwater study, an artesian well was chosen to represent an untreated and uncontaminated groundwater source of drinking water. The location of the artesian well was in an area just north of Bay St. Louis, Mississippi. Ten models of activated-carbon home water treatment units were selected and evaluated. The ten models were selected from the list of 31 models previously tested during Phases 1 and 2 of GSRI's contract with EPA (Contract No. 68-01-4766). Each model was challenged with spiked artesian well water during duplicate test runs at the well site. The spiked compounds were 1,1,1-trichloroethane, carbon tetrachloride, trichloroethylene and tetrachloroethylene and the target level of each spiked compound was 50, 20, 50, and 50 µg/l (ppb), respectively. Performance parameters routinely monitored were 1) the four spiked halogenated organics (HO); 2) nonpurgeable total organic carbon (NPTOC); 3) standard plate count (SPC); 4) endotoxin; 5) total organic halide (TOX); and 6) silver. Only the water samples from models incorporating silver in the carbon matrix were analyzed for silver. Other complimentary data, including gallons of water processed, water temperature and time and date of sampling were determined and recorded for each unit. The performance testing and sampling schedule used in the groundwater study deviated in two respects from the protocols previously described

TABLE 3. PHYSICAL DESCRIPTION OF ACTIVATED-CARBON MODELS TESTED

Unit	Rated capacity (gallons/liters)	Approximate volume of carbon (cm ³)	Carbon weight (g)	Iodine number	Test flow rate (gpm/lpm)
<u>Line bypass</u>					
Aquacell Bacteriostatic	2000/7571	663	417 ^a	867	0.9/3.2
Aqualux, Model CB-2	2000/7571	1760	1150 ^a	966	0.8/3.0
Aqualux, Model HB	2000/7571	880	575 ^a	970	0.6/2.3
Continental, Model 350	720/2726	7079	3402	960	0.6/2.3
Culligan, Model SG-2	4000/15142	2470	1708	980	1.0/3.8
Everpure, Model QC4-THM	1000/3785	1650	765	1223 ^b /798 ^c	0.6/2.3
Seagull IV	1000/3785	739 ^d	300	434 ^d	0.8/3.0
<u>Faucet Mount</u>					
Hurley Town and Country	4000/15142	1765	895	913	0.8/3.0
Instapure, Model F-1C	200/757	50	27	950	0.5/1.7
Water Washer, Model 1000	1000/3785	310	70 ^a	845	0.5/1.7
<u>Stationary</u>					
Sears Taste and Odor	3000/11356	660	398	920	2.3/8.7
<u>Pour-through</u>					
Fillbrook Pour-through	300/1136	146	97	788	0.04/0.2
<u>a</u> Impregnated with silver					
<u>c</u> from cartridge number 2 Everpure QC4-THM					
(includes binder and powdered carbon)					
<u>b</u> from cartridge number 1 Everpure QC4-THM					
<u>d</u> block of carbon and binder					

in the experimental section. A range finding run was not performed and the "running water" chemical samples were collected immediately after the biological samples (after the appropriate hold-up volume of each unit was discarded). The THM compounds were not detected in this water source.

Results of the Groundwater Study

Halogenated Organics (HO) Removal

The summary performance of each home-water-treatment model is reported in Table 4 and Figure 5. The data indicate that the selected models (at least one model from each of four basic configurations) were effective in removing the spiked level of HO from the well water (76 to 99 percent). Efforts to compare models with one another may result in biased interpretation unless the various experimental and individual unit parameters, such as design features, capacity, flow rate, and spiked well water halogenated organic levels are considered. The summary Table 4 is organized according to type of model since units within each category are designed to operate generally in the same manner.

Unit effectiveness in removing halogenated organics was determined by plotting the percent reduction of halogenated organics versus gallons processed for each of two trial runs. The average of the two plots appear in Figure 5. Percent halogenated organic reduction was calculated by dividing the area under the average curve with the total area of the plot (gallons x 100 percent). An additional criterion used to evaluate the effectiveness of HO removal is the amount of HO (g) removed (average influent load x unit rated volume capacity x percent reduction = amount removed). The amount of HO removed is determined by the average HO spike concentration, which varied from 128 to 158 ppb during the groundwater test in Phase 3. In addition, if comparisons between types of units are made, amount as well as percent reduction of HO should be considered.

Table 5 breaks down the halogenated organic class into the four specific compounds which were spiked into the groundwater. The range of percent reductions for each of the four spiked compounds are listed separately for the filter models tested in Phase 3. It is evident from this data that chemical reductions on the whole are much better than those observed in laboratory studies on New Orleans water. This is probably due to two primary factors. The first is the type of chemical compound and the second involves the overall bulk organic loading of the source water (New Orleans tap water is 4-10 times greater in organics than the ground water source as measured by NPTOC).

Carbon tetrachloride and 1,1,1-trichloroethane were generally the first two compounds to "break through" the activated-carbon units. Trichloroethylene and tetrachloroethylene were the last to "break through," if ever, indicating that these two compounds are more strongly absorbed on activated-carbon than either carbon tetrachloride or 1,1,1-trichloroethane. A plausible explanation for these observations is that both trichloroethylene and tetrachloroethylene are unsaturated halo-carbons (contain double bonds). Other

TABLE 4. SUMMARY PERFORMANCE: HALOGENATED ORGANICS REMOVAL DURING RATED LIFETIME FOR LINE BYPASS, FAUCET-MOUNT, STATIONARY, AND POUR-THROUGH UNITS IN THE GROUND WATER STUDY

Unit	Rated capacity (gallons/liters)	Average influent concentration (ppb)	Total influent load (g)	Amount removed by activated carbon	
				(g)	(%)
<u>Line bypass</u>					
Aqualux CB-2	2000/7571	132	1.00	0.99	99
Continental Model 350	720/2725	134	0.37	0.37	99
Culligan Model SG-2	4000/15142	144	2.18	2.16	99
Everpure QC4-THM	1000/3785	158	0.60	0.59	99
Seagull IV	1000/3785	158	0.60	0.58	97
Aquacell	2000/7571	132	1.00	0.97	97
<u>Faucet-Mount</u>					
Hurley Town and Country	4000/15142	143	2.17	2.10	97
Water Washer Model 1000	1000/3785	128	0.48	0.36	76
<u>Pour-Through</u>					
Filbrook	500/1892	143	0.27	0.25	91
<u>Stationary</u>					
Sears Taste and Odor	3000/11356	152	1.73	1.60	90

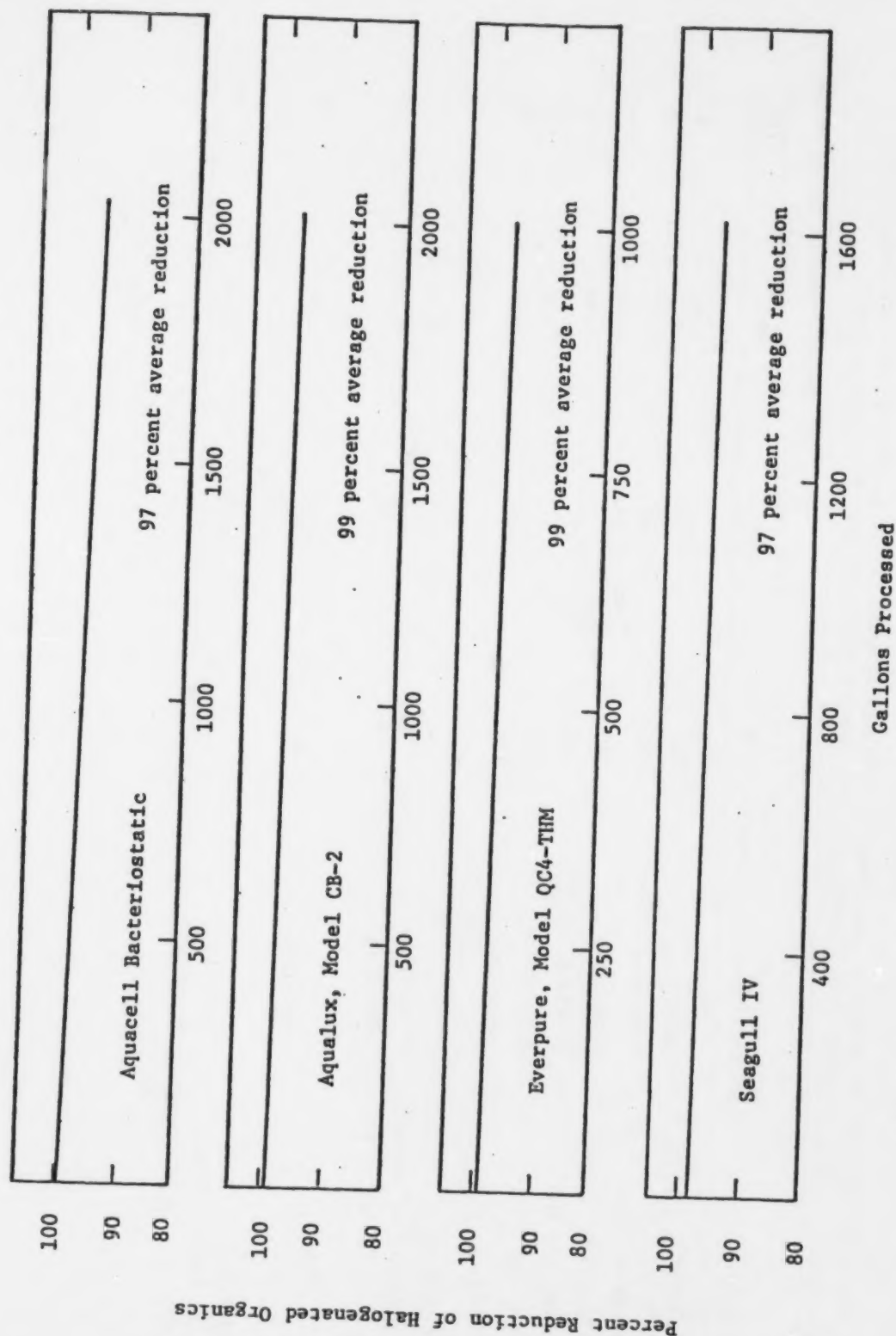


Figure 5. Summary performance of activated-carbon units for halogenated removal.

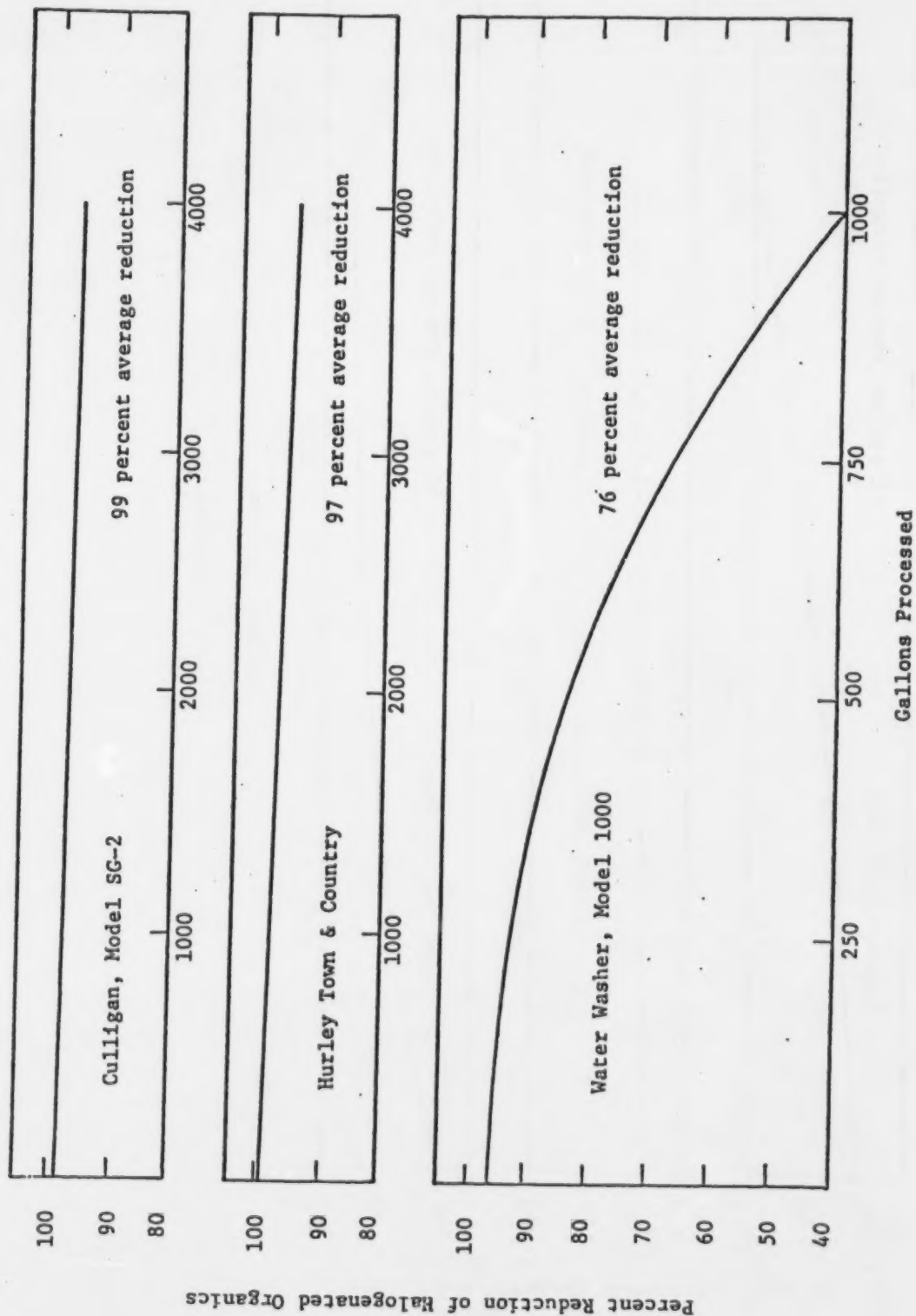


Figure 5 (continued)

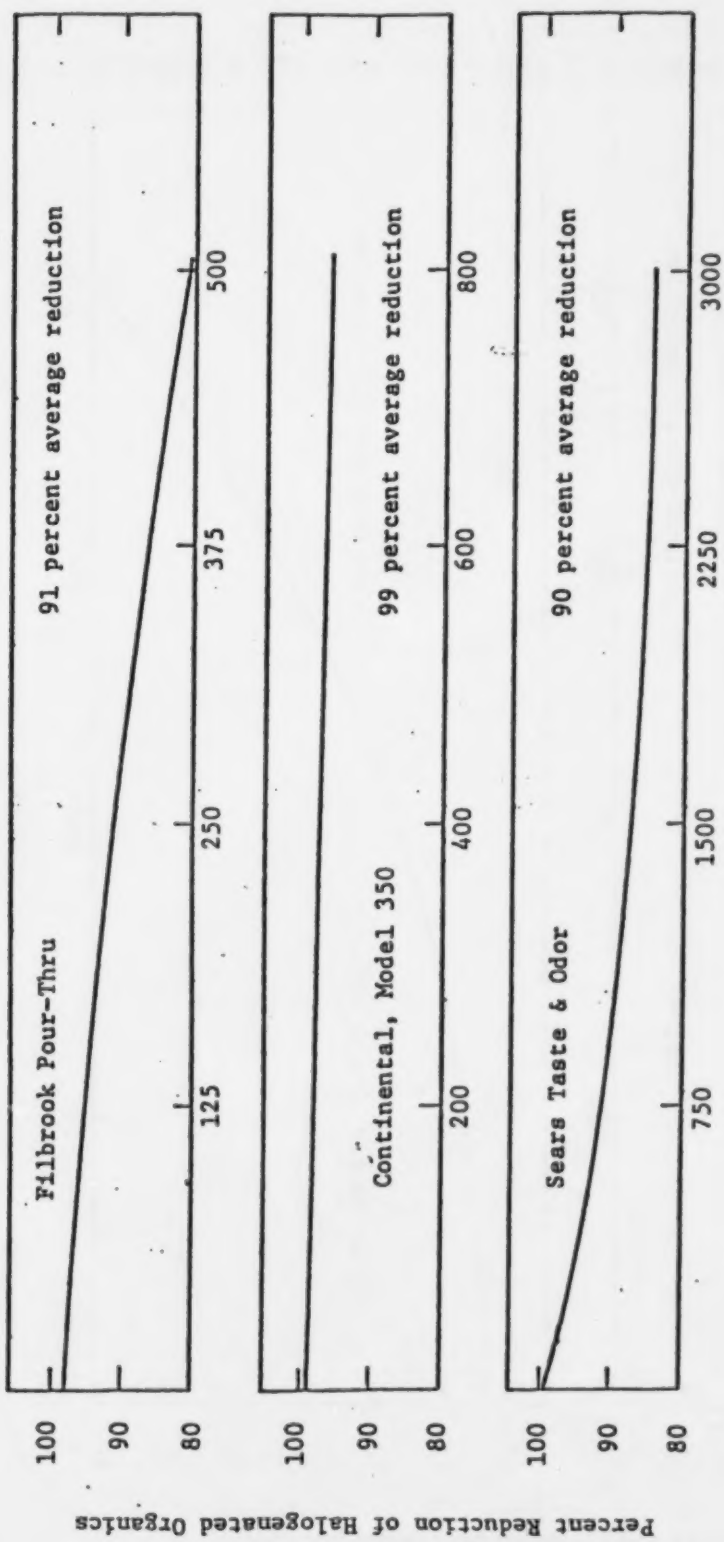


Figure 5 (continued).

TABLE 5. RANGE OF PERCENT SPECIFIC HALOGENATED ORGANIC (HO) REDUCTION FOR LINE BY-PASS
FAUCET-MOUNT, STATIONARY, AND POUR-THROUGH UNITS IN THE GROUNDWATER STUDY

Unit	Rated capacity (gallons/liters)	Range of average percent HO reduction (beginning-ending)			
		1	2	3	4
<u>Line bypass</u>					
Aqualux CB-2	2000/7571	99-99	98-96	99-99	99-99
Continental Model 350	720/2725	99-99	99-99	99-99	99-99
Culligan Model SG-2	4000/15142	99-98	99-98	99-99	99-99
Everpure QC4-THM	1000/3785	99-99	95-99	99-99	99-99
Seagull IV	1000/3785	98-95	98-97	98-97	98-97
Aquacell	2000/7571	99-93	99-95	99-98	99-97
<u>Faucet-Mount</u>					
Hurley Town and Country	4000/15142	99-93	97-94	99-98	99-99
Water Washer Model 1000	1000/3785	96-40	95-55	95-70	99-62
<u>Pour-Through</u>					
Fillbrook	500/1892	99-70	98-77	95-90	99-98
<u>Stationary</u>					
Sears Taste and Odor	3000/11356	98-70	98-80	99-96	99-98
<u>1,1,1-trichloroethane</u>					
<u>carbon tetrachloride</u>					
<u>trichloroethylene</u>					
<u>tetrachloroethylene</u>					

studies in the literature have shown that unsaturated compounds are absorbed on activated-carbon more strongly than their saturated analogs. The original HO removal data for each trial of each unit are presented in Tables S4 through S23 of the "Phase 3/Final Report - Supplemental Data."

Nonpurgeable Total Organic Carbon (NPTOC) Removal

The summary of each unit for NPTOC removal is reported in Table 6. Since low levels of influent NPTOC were found in the artesian well water (at or near the detection limit of the Dohrmann Model 54 TOC analyzer), data points of NPTOC reduction and addition were observed in a scattered pattern. Consequently, calculation of NPTOC reduction would be statistically meaningless under the test conditions (challenge NPTOC level) used in the groundwater study. The information included in Table 6 can be used to estimate the background level of organic material with which the filters were challenged.

Nonpurgeable Carbon Absorbable Organic Halide (NPCAOX) Removal

Results of total organic halide (TOX = POX + NPCAOX) indicated that the influent levels of nonpurgeable carbon absorbable organic halide (NPCOAX) were between 0-20 µg/l. These influent levels were at or near the detection limit of the analytical method (standard deviation $\pm$ 100 percent). Therefore, the determination of percent reduction of NPCOAX in the spiked well water by activated-carbon units is not statistically meaningful. The original TOX data for each trial of each unit are listed in Table S55 of "Phase 3/Final Report - Supplemental Data."

Microbiological Parameters

Results of standard plate counts (SPC) indicated that average levels of SPC were somewhat higher (but the same order of magnitude) than corresponding levels observed in laboratory Phase 1 and Phase 2 studies. The following ranges of SPC levels were observed: 2-day stagnation samples ranged from 270 to 14,000; 5-day stagnation samples ranged from 10 to 350,000; and running water samples ranged from <10 to 71,000. Endotoxin levels ranged between 0.2 and 11.5 ng/ml. As in Phase 1 and Phase 2 studies, a correlation between SPC and endotoxin was not observed in the groundwater study.

Statistical evaluations of average test unit effluent (TUE) and control loop (CL) SPC and endotoxin samples for overnight, 2-day, and 5-day stagnation samples sets are listed in Table 7. Real increases in effluent SPC levels were measured on data sets where variances (F test) allowed comparisons to be made. These increases were similar to those observed in earlier test results in Phases 1 and 2. The overall levels of SPC bacteria were slightly higher than those observed in the previous laboratory work. Two possible reasons for average SPC levels in the groundwater study being somewhat higher than previous laboratory studies are that the source water was not chlorinated and that the average water temperature was 30°C with levels as high as 35°C being experienced occasionally.

Apparent increases and decreases in effluent endotoxin levels did not prove to be statistically significant when data was challenged at the 90 percent confidence level with the student "t" test. No definite trends or correlations in the endotoxin data could be established.

TABLE 6. SUMMARY PERFORMANCE: NPTOC REMOVAL DURING RATED LIFETIME FOR
LINE-BYPASS, FAUCET-MOUNT, STATIONARY, AND POUR-THROUGH UNITS IN THE GROUNDWATER STUDY

Unit	Rated capacity (gallons/liters)	Average influent concentration (ppb)	Total influent load (g)	Amount removed by activated carbon (g)	(%)
<u>Line bypass</u>					
Aqualux CB-2	2000/7571	407	3.1	*	*
Continental	720/2725	260	0.71	*	*
Culligan	4000/15142	350	5.3	*	*
Everpure	1000/3785	273	1.0	*	*
Seagull IV	1000/3785	273	1.0	*	*
Aquacell	2000/7571	407	3.1	*	*
<u>Faucet-mount</u>					
Hurley T&C	4000/15142	339	5.1	*	*
Water Washer	1000/3785	426	1.6	*	*
<u>Pour Through</u>					
Filbrook	500/1892	339	0.64	*	*
<u>Stationary</u>					
Sears T&O	3000/11356	281	3.2	*	*

*Due to the low levels of influent NPTOC (at or near the detection limit of the Dohrmann model 54 TOC analyzer) data points of NPTOC reduction and addition were observed in a scattered pattern. Therefore, calculation of NPTOC reduction would have limited value or meaning under the test conditions (challenge NPTOC level) used in the groundwater study.

TABLE 7. STATISTICAL COMPARISON OF STANDARD PLATE COUNT AND ENDOTOXIN DATA FROM TEST UNIT EFFLUENT AND CONTROL LOOP SAMPLES - GROUNDWATER STUDY

Parameter	Mean Value		
	A	B	C
Log ₁₀ SPC	3.48 (TUE) ^a	4.14 (TUE)	3.55 (TUE)
	2.77 (CL)	2.29 (CL)	2.52 (CL)
F test 90% confidence level ^b	Yes	No	Yes
t test 90% confidence level ^c	Yes	NA	Yes
Endotoxin	2.93 (TUE)	4.20 (TUE)	2.12 (TUE)
	4.46 (CL)	2.95 (CL)	2.55 (CL)
F test 90% confidence level ^b	No	Yes	Yes
t test 90% confidence level ^c	NA	No	No

A = 2-day stagnation sample

B = 5-day stagnation sample

C = overnight-stagnation sample

^a(TUE) = test unit effluent; (CL) = control loop

^bThe F test is a comparison of variances (i.e., yes, indicates that the variances of the two populations are comparable).

^cThe t test is used to test the hypothesis that two means do or do not differ significantly (i.e., no, indicates that the two populational means do not differ significantly).

Results of silver levels in well water filtered with silver-impregnated activated-carbon units indicated that effluent silver levels ranged from 0 to 28 ppb. These levels were somewhat higher than effluent silver levels (<1 to 12 ppb) observed in Phases 1 and 2. A plausible explanation for this observation is that the pH of the well water was about 7, whereas the pH of New Orleans tap water (used in Phase 1 and 2 laboratory studies) was approximately 9. Silver does not leach-out of the activated carbon as efficiently at higher pH as it does at lower pH. Despite the increased levels of silver, the silverized carbon units displayed no significant plate count bacterial level differences from the non-silverized carbon filters. The original data of SPC, endotoxin, and silver analyses for each unit trial are presented in Table S2 and in Tables S56 through S65 of "Phase 3/Final Report - Supplemental Data."

FIELD STUDY

Overview of Field Study

The bulk of home water treatment unit tests in this study (Phases 1 through 3) have been performed using New Orleans tap water as matrix. The possibility of differing qualities of the matrix water having an effect on the performance of the filter unit is acknowledged. The field studies were performed to generate limited performance data from test using differing sources of water (with hopefully a range of matrix effects) in an effort to determine to what extent a set of experimental laboratory test results from one location and source water can be used to predict performance at another location.

New Orleans tap water is characterized as a high pH, moderate total dissolved solids (TDS) type drinking water. Although the adsorption of most organic compounds is not affected by pH, there are organics whose ionic form, rate, and extent of adsorption will change under the pH ranges encountered in drinking water in this country. Accompanying these ionic configuration changes are changes in molecular size as well as polarity, hydrogen bonding, and other factors which affect the physical interactions between the water matrix, carbon adsorbent, and the organic compound. Another water matrix factor potentially affecting the performance of some carbon units is the ability of water to leach inorganic material from the adsorbent bed. This factor is important since it has been suggested that the inhibition of bacterial growth on the carbon beds can be achieved by controlled release of a silver complex impregnated within the carbon bed. It is also believed that a low pH/low TDS water is a more active water matrix for leaching off silver. Because of these potential matrix effects, the field study element of this project was added so that any differences in the matrix effects using different water sources could be observed. Four home water treatment models were tested using the drinking water in four cities in the United States: 1) Miami, Florida; 2) Pico Rivera, California; 3) Atlanta, Georgia; and 4) Detroit, Michigan. Two of the field locations were from groundwater (well water) sources, Miami and Pico Rivera. The other two, Detroit and Atlanta, represented surface water supplies. Miami was selected specifically for this

study since it represented a groundwater source with a high organic loading. The other three sites were chosen on the basis of cost savings realized from non-related ongoing contract work at these locations.

The performance testing and sampling schedule used in the field studies deviated from the protocols (Figures 1 and 2) previously described in the experimental section in the following respects:

1. Filter tests in Atlanta, Pico Rivera, and Detroit were targeted for a duration of eight days which consisted of five days of continuous stress cycling and three days of stagnation.
2. The Miami tests were targeted for a duration of 30 days stress cycling since this test was not restricted by other EPA work and since at least one set of field data could be obtained without the rapid test acceleration required by an eight-day test.
3. The field studies were conducted using the two portable, four-position test manifolds which are described schematically in Figure 6. The two manifolds were similar to the multiposition test manifold used in the laboratory evaluations. Each manifold consisted of flow meters, gallonage meters, solenoid valves, pressure gauges, and the timer cam control system. A 50-foot coil of tubing was incorporated into the set-up to ensure an adequate holdup volume to provide a representative control-loop sample for comparison with unit effluent samples.
4. Samples were iced-down immediately after collection and shipped via air freight to New Orleans. Samples were plated for SPC analysis within 48 hr after collection. Chlorine samples were analyzed on-site and nondegrading samples such as silver were shipped back to New Orleans with the test equipment.
5. Each of the four models were tested in duplicate (i.e., no "range finding" run).

Results of the Field Study

Trihalomethane (THM) Reduction

The average percent THM reduction performance curves for each of the four models tested is presented in Figures 7 through 10. Each figure illustrates calculated percent THM reductions from all four field locations with New Orleans experimental results presented for comparison purposes. In studying these plots a couple observations are made regarding the data and further explanation is offered below to clarify some of the limitations of this data.

In Pico Rivera, and to some extent Detroit, the levels of THM in the source water was low. At these levels the errors in analysis become a significant factor in data interpretation. Many times the error in the analysis can be comparable to or larger than the responses being monitored.

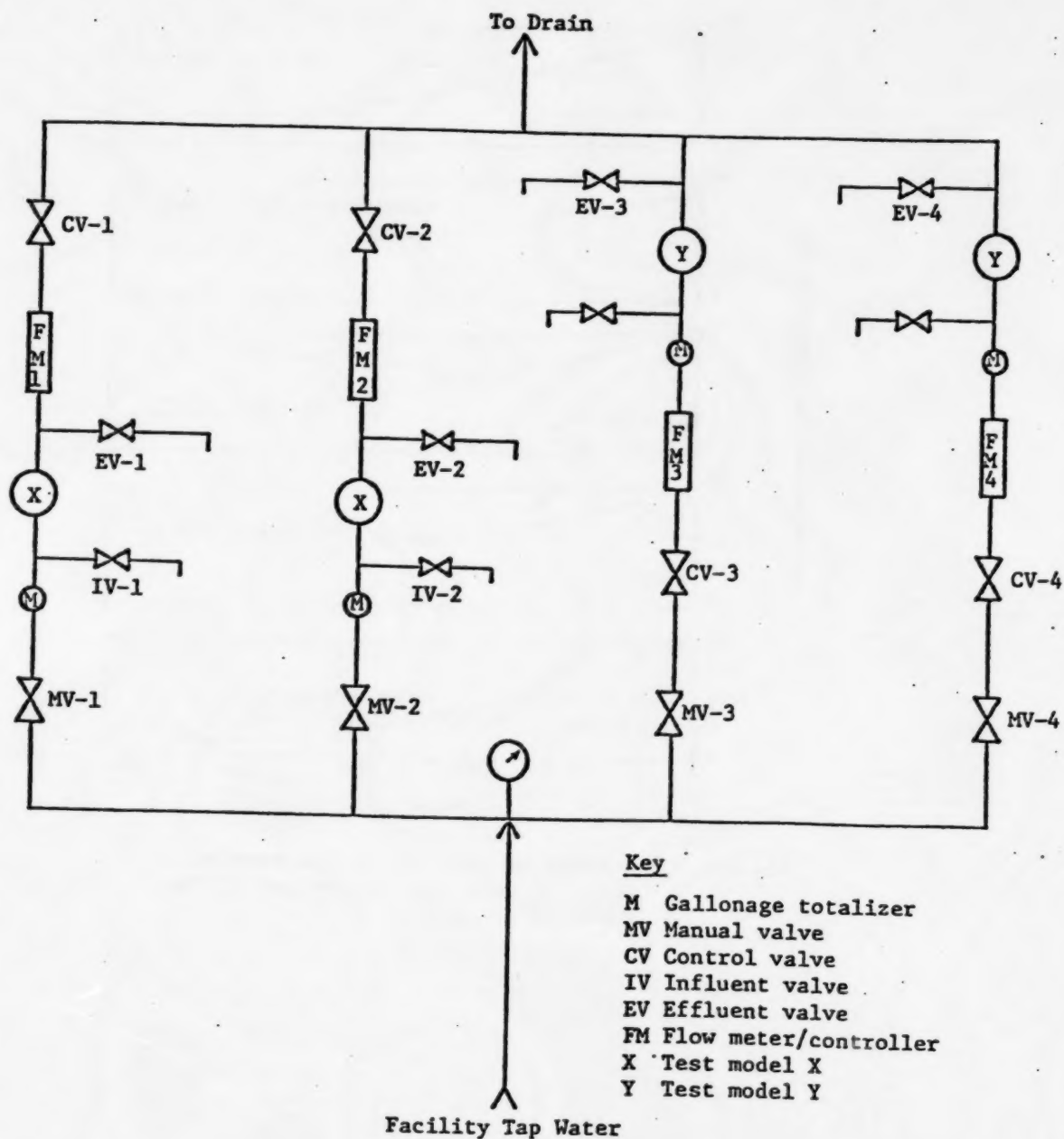


Figure 6. General flow schematic of test manifold for conducting the field studies.

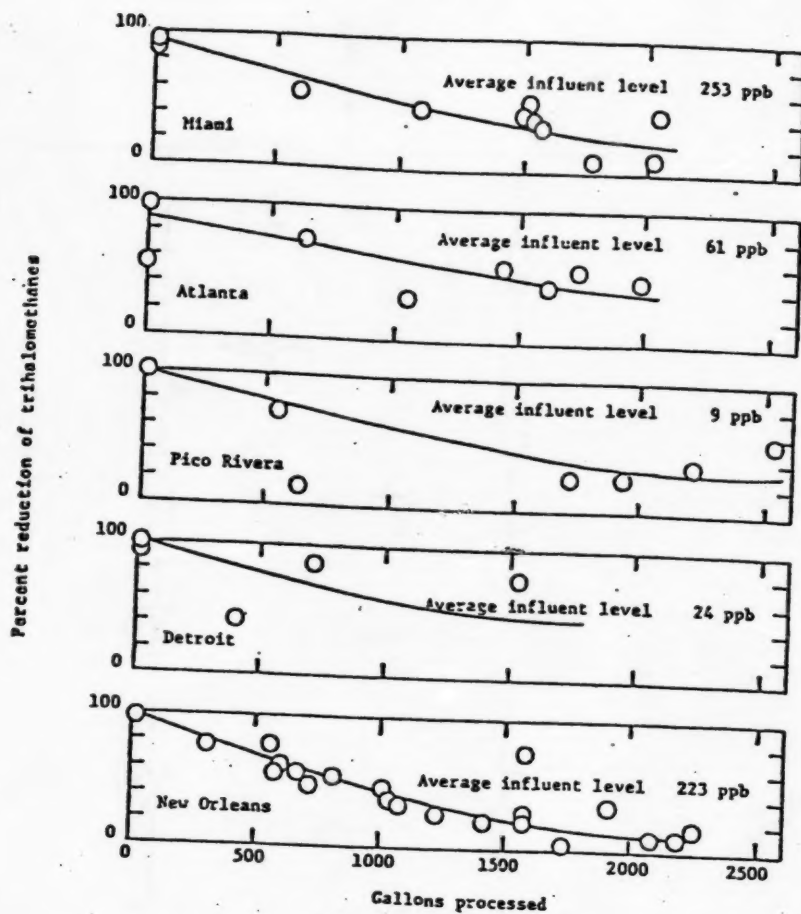


Figure 7. Summary performance of the Aqualux, Model HB unit for THM removal in the field of study.

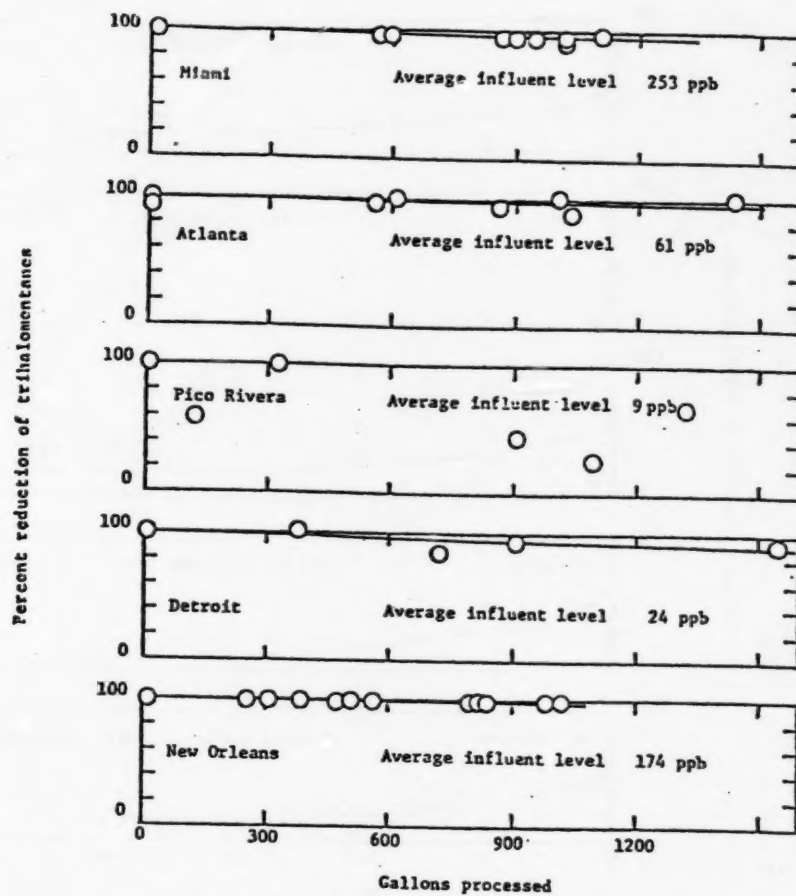


Figure 8. Summary performance of the Everpure, Model QC4-THM for THM removal in the field study.

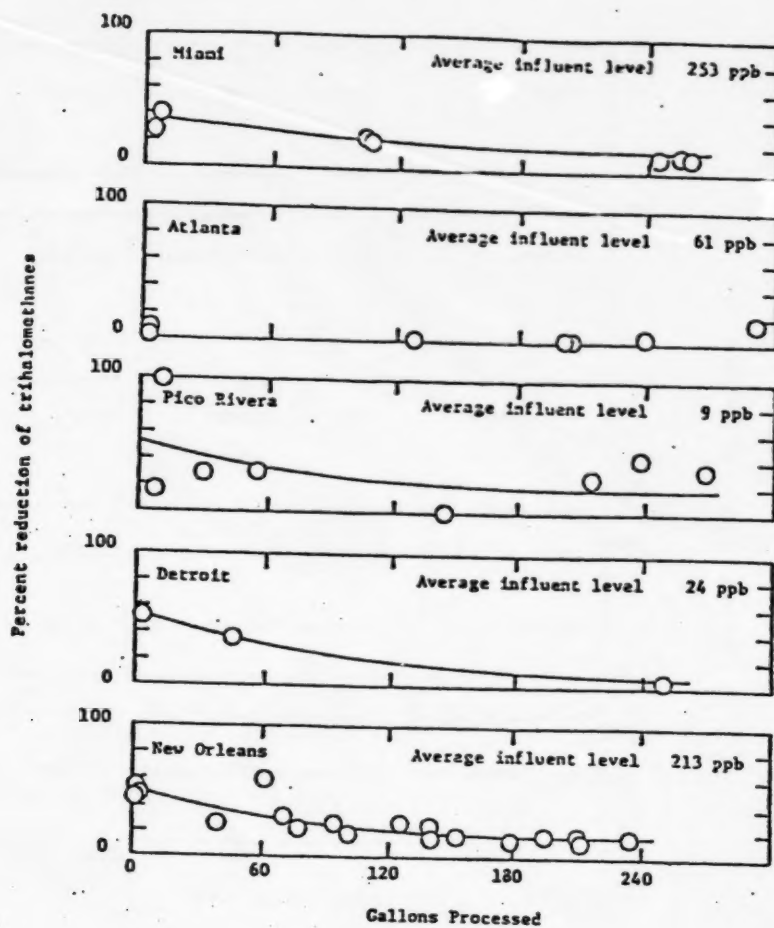


Figure 9. Summary performance of the Instapure, Model F-1C for THM removal in the field study.

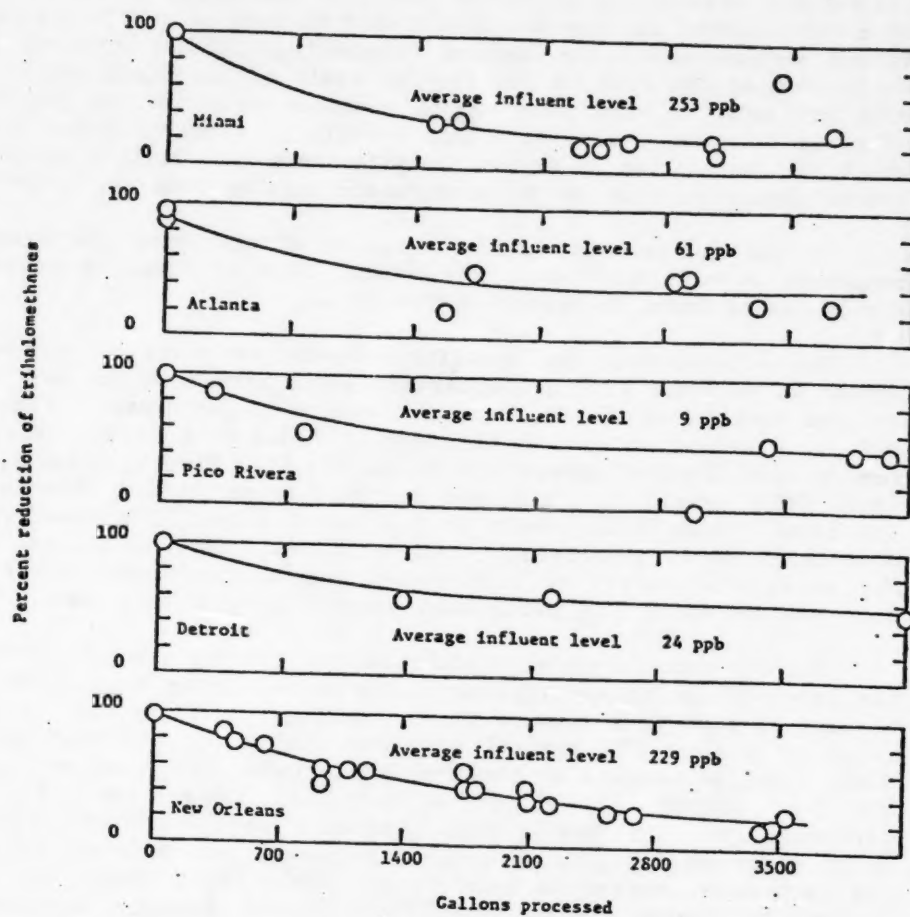


Figure 10. Summary performance of the Sears Taste and Odor unit for THM removal in the field study.

Performance evaluations at these levels of contamination have a large amount of error inherent in them and should only be used as a guide in assessing the filter performance. The second compounding factor involved in limiting usefulness of the data is the limited scale of the field study. Units were only evaluated in duplicate and in a couple of situations during the study only one unit was evaluated. This results in a very limited data base upon which conclusions can be drawn. Despite these data limitations the following trends appear evident in the performance results from the field study test.

Of the filters tested the relative effectiveness for removal of THM compounds appears to remain the same. This is visually evident wherever curves can be drawn in Figures 7 through 10.

The effectiveness for specific compound or class of compound removals appear to decrease with a increased organic burden in the matrix. This can be seen best in the Sears Taste and Odor units performance (Figure 10) curve and to a lesser extent in the Aqualux Model HB's curves (Figure 7). The removal efficiencies appear greater in the Pico Rivera, Atlanta, and Detroit (with NPTOC levels 0.6, 1.2, and 1.7 ppm, respectively) than in New Orleans and Miami (with NPTOC levels of 2.1 and 7.1 ppm). The observation is less obvious in units performing at the extremes. This is further supported by the excellent removal of halogenated organic compounds in the groundwater test series where the background organic levels were less than 1.0 ppm.

Further conclusions or calculations of average percent reductions exceed the level of confidence implied in the data. Table 8 has been tabulated to attempt to provide a summary format for the results of the field study. The range of percent THM removal has been listed for all four models in each field location as well as the average influent THM level experienced during the test period. It should be noted in Table 8 that the units which performed well in New Orleans performed well in other locations. The relative rankings appear to remain the same. The original THM removal data for each model tested in each of the field study cities are presented in Tables S24 through S51 of the "Phase 3/Final Report - Supplemental Data."

Nonpurgeable Total Organic Carbon (NPTOC) Removal

Plotting the data sets of NPTOC for each of the four filter models generally produced scattered patterns (i.e., NPTOC reduction was not described by smooth asymptotic curves). Consequently, the determination of average percent NPTOC reduction is limited in value for the comparison of unit performance in each of the respective cities. Table 9 lists the respective data set ranges of percent NPTOC reduction for each model. Generally, each model removed the most NPTOC at the beginning of the test with the percent NPTOC reduction decreasing with the amount of water processed. Some NPTOC data sets deviated significantly from the general population. It is emphasized that these data sets may be valid since one aspect of carbon units is that unloading under stress occurs and may result in the transfer of collected matter to the product water. The reliability of NPTOC data from Atlanta is questionable because of the unexpected and unexplained formation of a precipitate during some sample analyses. In

TABLE 8. SUMMARY PERFORMANCE: THM REMOVAL OF ACTIVATED-CARBON UNITS IN THE FIELD STUDY

Unit	Data Set Range*				
	Field Locations				
	Atlanta	Pico Rivera**	Miami	Detroit	New Orleans
Aqualux, Model HB	31-97	14-99	10-94	41-99	3-99
Instapure, Model F-1C	0-37	0-99	10-39	3-51	12-53
Sears Taste and Odor	20-91	0-99	16-99	50-99	14-99
Everpure, Model QC4-THM	89-99	25-99	93-99	84-99	98-99
Average THM influent level during test period (ppb)	61.0	9.0	253	24.4	203

* Data set = the range of percent THM reduction values experienced during the test period (ending - beginning).

** Low influent levels of THM (near the detection limit of analytical method) requires caution in the interpretation of THM reduction data.

TABLE 9. SUMMARY PERFORMANCE: NPTOC REMOVAL OF ACTIVATED-CARBON UNITS IN THE FIELD STUDY

Unit	Data Set Range*				
	Location				
	Atlanta**	Pico Rivera	Miami	Detroit	New Orleans
Aqualux Model HB	0**-39	13-65	2-70	17-64	10-65
Instapure Model F-1C	0-12	0**-33	0**-17	0-17	0**-25
Sears Taste and Odor	8-55	8-82	0-74	1-37	4-66
Everpure, Model QC4-THM	9-74	40-79	15-93	17-80	45-75
Average NPTOC influent level during test period (ppb)	1194	570	7076	1716	2188

* Data set = percent reduction determined for individual sampling event (ending - beginning).

** NPTOC additions observed (i.e., unloading of organics from the carbon bed)

*** NPTOC data from Atlanta samples are questionable due to the formation of a precipitate during some of the analyses.

general, matrix effects did not appear to significantly affect the performance of each filter model in removing NPTOC from the respective source waters. The original data of NPTOC removal for each trial of each unit are presented in Tables S24 through S51 of "Phase 3/Final Report - Supplemental Data."

Microbiological Parameters

Tables S66 through S81 in "Phase 3/Final Report - Supplemental Data" lists the SPC, endotoxin, free chlorine, and silver data as a function of water processed by each unit in each field test. In general, effluent SPC levels (range 1-30,000) were higher than influent SPC levels (range 1-1800) with fewer reversals observed than in the New Orleans laboratory tests. The magnitude of the difference between influent and effluent (SPC) levels was in the same range (orders of magnitude) as those in the laboratory tests with plate count level increases being observed for both silverized and non-silverized units. Endotoxin levels (range 0.5-6.4 ng/ml) were similar to laboratory results both in magnitude and in the number of reversals observed in consecutive sampling events. The data base of plate count levels and endotoxin concentrations was not large enough in any one category to permit a quantitative statistical analysis of increases in plate counts or endotoxins to be made.

Significant free chlorine levels (up to 1.4 ppm) were present in Miami, Atlanta, and Detroit samples, and there was no chlorine present in the untreated Pico Rivera well water. Increased free chlorine levels were not reflected in lower SPC levels. This observation is consistent with stagnant-water and filtered-water samples. Silver sample analyses (from Aqualux HB unit) indicated variable effluent silver levels (1-21 ppb) in the different source waters and within respective trial runs. All effluent silver levels were higher than influent levels, but were well below the maximum contaminant level (MCL) of 50 ppb. Again, as in the laboratory studies (Phases 1-3), the bacterial inhibition effects of silver were not observed. No silver analysis was obtained for the Atlanta test due to loss of samples.

HOME STUDY

Overview of Home Study

Another question of concern in this program was whether accelerated (laboratory), as opposed to actual use (home), testing biased the performance of some activated-carbon units. Since few published reports addressed this question, three filter types were challenged with New Orleans tap water under accelerated (at GSRI) and nonaccelerated (three homes) experimental conditions to attempt to evaluate the impact of accelerated testing on performance data. The three filter types were line bypass (Aqualux, Model HB), stationary (Sears Taste and Odor, in line), and faucet attached (Instapure, Model F-1C). Performance parameters monitored were THM and CCl_4 , NPTOC, SPC, endotoxin, free and total chlorine, and silver (were applicable). Other complimentary data, including gallons of water processed, water temperature, and time and date of sampling were determined and recorded for

each unit. The performance testing and sampling schedule in the home study deviated from the laboratory protocols previously described in the experimental section (Figures 1 and 2) in the following ways: 1) a single trial only was performed, 2) the use-rate (gallons) of each unit was estimated at each sampling event, 3) the flow rates of each unit were determined by the time needed to obtain a fixed volume of sample, and 4) the frequency of sampling for each unit was more random than the sampling events used in the laboratory studies (ie., 0, 25, 50, 75, 100 percent of capacity).

Results of the Home Study

Trihalomethane (THM) Removal--

Figures 11 through 13 are plots representing percent trihalomethane reduction for each unit in the home (nonaccelerated) and laboratory (accelerated) tests. The data points for each model in the laboratory study were determined and previously reported in Phase 1 of this program. The gallons of water processed by the Instapure and Aqualux units (non-accelerated tests) were estimated by multiplying the number of elapsed days of the test by the estimated gallons per day (gpd) usage for each unit. The gpd estimates for the Aqualux unit were determined from daily average use-rate measurements using the accumulation meter on the unit. However, this meter operated accurately for only the first quarter of the test period. The estimated daily use-rate for the Instapure unit was adjusted upward with respect to the Aqualux unit since the Instapure was used in a three adult household and the Aqualux was used in a two adult, one child household. The average gpd use-rate for the Sears unit was based on elapsed test days and the readings from the installed accumulation meter. The location, test dates, occupancy of household, and estimated use-rate for each unit are listed in Table S85 in the "Phase 3/Final Report - Supplemental Data."

The respective individual data sets describing THM reduction for the Instapure, Model F-1C and Aqualux, Model HB are essentially the same in both home and laboratory tests. The correlation of laboratory to home test THM reduction appeared to be valid even though the average rate of test acceleration was 19x for the Instapure and 76x for the Aqualux unit (average rate of acceleration = $\text{gpd lab test} / \text{gpd home test}$). Test flow rates and average challenge THM concentrations were different in the home and laboratory tests; however, as previously noted in Phase 1 and 2 reports these two factors did not appear to significantly affect ($\pm 10\%$) THM reduction capabilities of carbon units that were operated with short contact times (~ 1 min or less) between the challenge water and activated carbon.

The home test for the Sears unit indicated a lower THM reduction profile (approximately 24 percent) than the Phase 1 laboratory tests. The average rate of test acceleration for the Sears test was 37X. The apparent difference in THM reduction between the home and laboratory tests has not been completely rationalized; however, the Sears cartridges, as with many other brands, were not marked with specific lot numbers. Consequently, the home test may have been performed with an off-lot of activated-carbon. Tables S52 through S54 in "Phase 3/Final Report - Supplemental Data" present the original THM removal data for each unit in the home study.

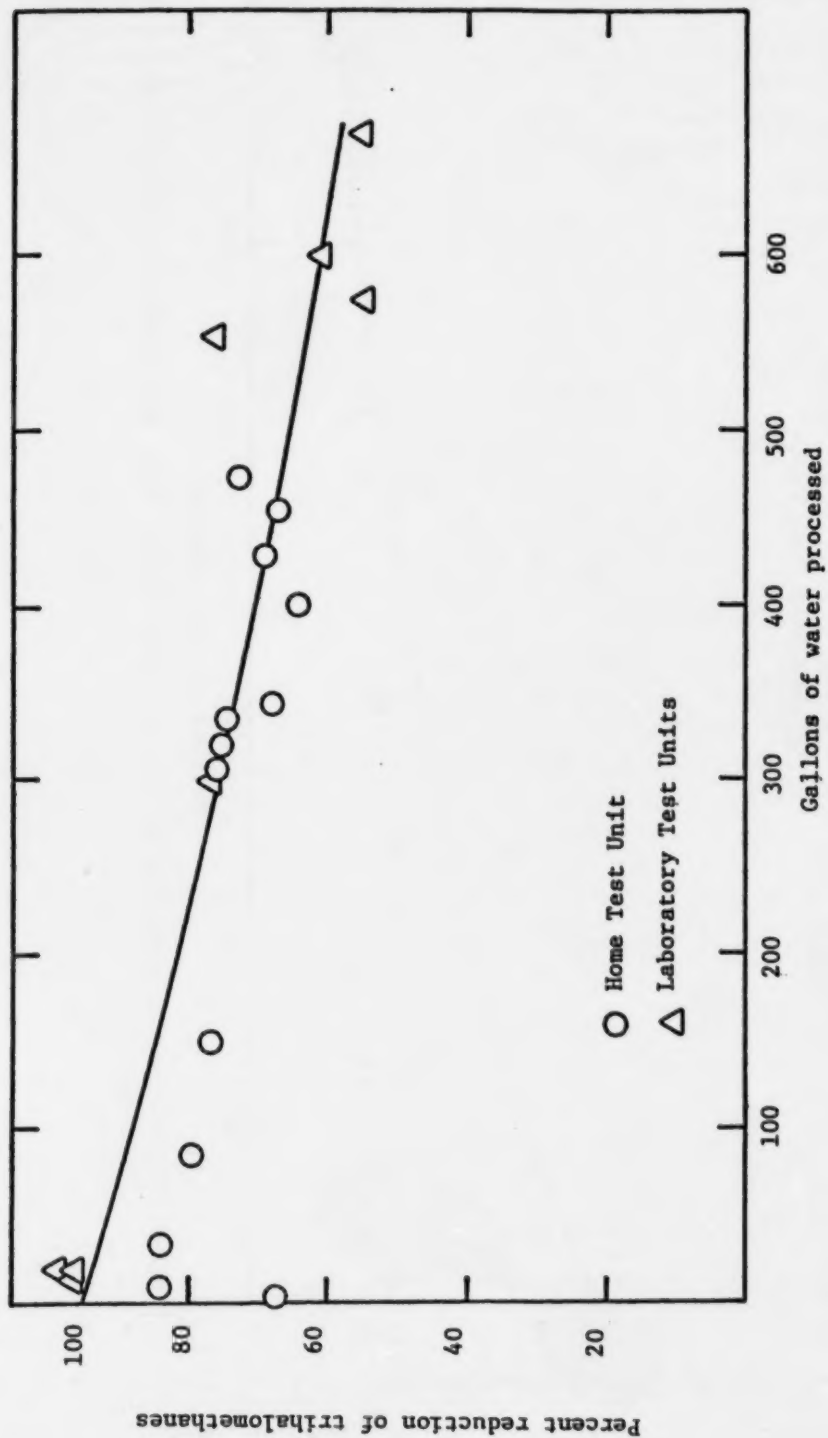


Figure 11..Percent THM reduction for the Aqualux, Model HB unit - home and laboratory tests.

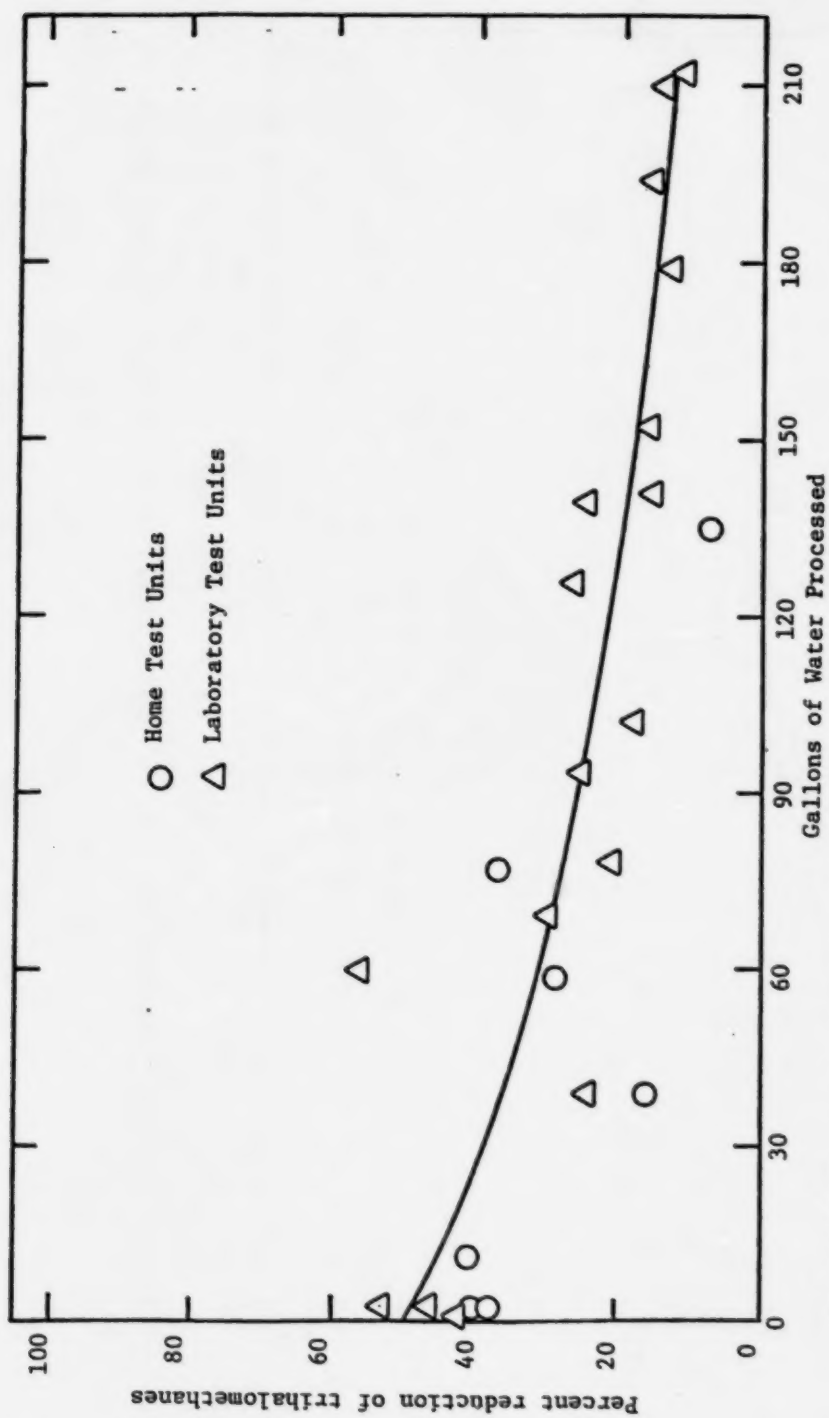


Figure 12. Percent THM reduction on the Instapure, Model F-1C unit - home and laboratory tests.

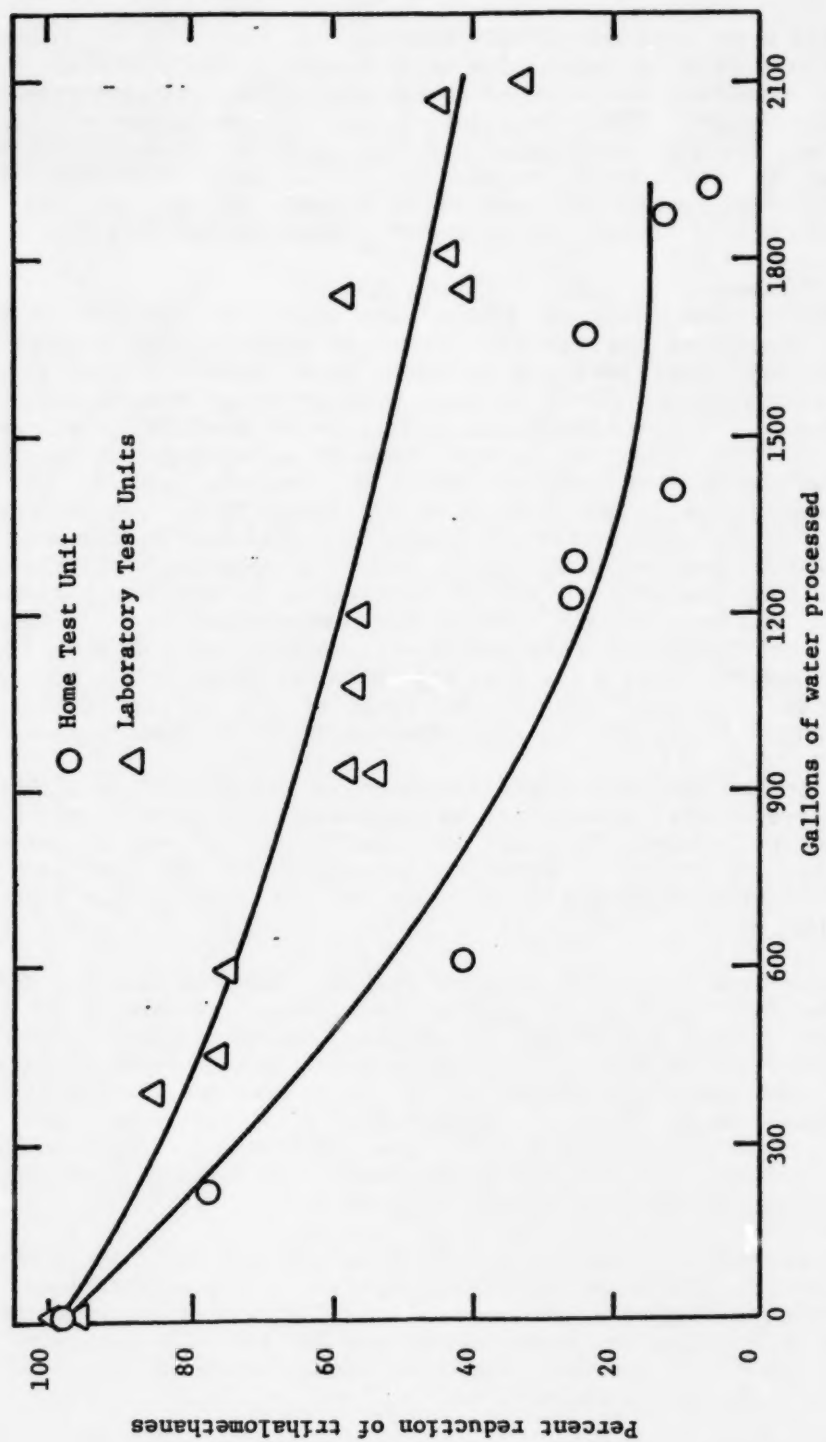


Figure 13. Percent THM reduction for Sears Taste and Odor unit - home and laboratory tests.

Nonpurgeable Total Organic Carbon (NPTOC) Removal

NPTOC data sets from the respective units tested in the home study were similar (both in magnitude and pattern) to the respective data sets from the Phase 1 laboratory study. NPTOC data sets ranged between a low of 0 to a high of 48 percent for the Sears Taste and Odor unit, 21 to 40 percent for the Aqualux Model HB, and 0 to 26 percent for the Instapure Model FIC. The original data of NPTOC removal for each trial of each unit are presented in Tables S52 through S54 of "Phase 3/Final Report - Supplemental Data."

Microbiological Parameters

Bacterial (SPC) and endotoxin levels were generally the same as the levels observed throughout the Phase 1 laboratory studies. The pattern of influent and effluent data sets was variable, with reversals from higher effluents to higher influent levels or vice versa occurring between consecutive sampling events. Moderate increases in average effluent SPC levels were observed for all three filter models when compared to average control loop levels although, only the Aqualux Model HB increase proved to be statistically significant. The data from the Sears Taste and Odor and Instapure Model F-1C did not provide statistically significant differences in control loop and test unit effluent levels when challenged with the student "t" test statistical criteria of significance at a 90 percent confidence level. Average increase in SPC levels were determined for the units evaluated under non-accelerated test conditions; Aqualux Model HB - +0.3 log SPC; Sears Taste and Odor - +0.6 log SPC; and Instapure Model F-1C - +0.4 log SPC. These values are well within the range of the average overnight increase in bacterial levels (+1 log SPC) experienced in the Phase 2 studies.

Endotoxin results detailed slight increases in average levels although none of these increases proved to be statistically significant when challenged with the student "t" test of significance at the 90 percent confidence level. The levels of endotoxin experienced in the home studies were not significantly different from those in the Phase 1 and Phase 2 laboratory studies.

Limited data from the home studies indicate the validity of using accelerated laboratory testing to provide an accurate assessment of the effectiveness of carbon filtration in removing trace organic chemical contaminants from drinking water. Organic chemical removals and bacterial aspects of the home test were comparable to those obtained for laboratory test with the exception of the Sears Taste and Odor THM reduction curve. A larger data base would be required to assure the positive correlation between laboratory (accelerated) test and home (actual use) test although preliminary data indicate the laboratory test provide valid data.

These home (actual use) test do not indicate the applicability of using test results from one laboratory test to extrapolate filter effectiveness on home applications with another water source. An indication of the effectiveness of carbon filtration on other water sources and the agreement of New Orleans test data with the data from other source waters was provided in the earlier section on field studies.

Tables S82 through S84 of the "Phase 3/Final Report - Supplemental Data" list data on SPC endotoxin, chlorine, and silver (Aqualux Model HB only) for each unit in the home study.

BACTERIAL LEACHING STUDIES

Faucet Bacterial Flushing Study

Overview

A major concern of investigators and informed consumers has been the effect of point-of-use water treatment devices on the bacterial quality of the treated water. However, before any conclusions concerning the bacterial content of treated water can be drawn, a broad and realistic data base on influent bacterial levels must be established for comparison with the various effluent bacterial levels of treatment devices. The following experiments are designed to expand the information available on some of the factors proposed to affect the bacterial quality of both filtered and unfiltered drinking water.

Currently, most major drinking water systems incorporate a disinfection procedure into their water treatment process. The disinfection usually involves dosing with chlorine or a chlorine derivative such as chloramine. Both disinfection procedures provide a level of residual protection for the distribution system, but dissipation of the disinfection agent to less than effective levels usually occurs within 48 hr. Consequently, the comparison of effluent bacterial levels from point-of-use devices with bacterial levels in the distribution mains is misleading or biased. The comparison of respective unit effluents should be made with bacterial levels in the water available to the consumer at the point of use, usually the kitchen faucet. This comparison is more accurate and realistic since the added effects of the transport of water through minor street mains, residential service mains, and plumbing systems within the house are included.

One factor that must be considered is the effect of the kitchen faucet. Many types of kitchen faucets are currently available and are in use throughout the United States. Most of the newer faucets include an aerator which provides uniform flow and aeration, while many older faucets do not have an aerator. Another dispensing feature available in many kitchens is a spray attachment. Each of these hardware fixtures provides a source of water for human consumption, and each fixture has its own characteristic internal design which includes areas of stagnant or semi-stagnant flow patterns. Endogenous bacteria, which are present in most drinking waters, will lodge, multiply, and subsequently rinse out of all faucets. Consequently, this element of the EPA study was designed to characterize and evaluate the bacterial flushing from three types of water supply fixtures: 1) kitchen faucet with aerator, 2) kitchen faucet without aerator, and 3) kitchen spray attachment.

Experimental Protocols

The faucets and spray attachment were assembled and plumbed as shown schematically in Figure 14. The faucets were Peerless Model 9210 and 9510 with spray attachment, and were mounted on a plywood base for easy manipulation. The spray attachment was removed from the faucet body and plumbed directly into the water line to avoid the undesired interplay normally found between faucet and spray attachment. The spray attachment nipple and hot water connections on both faucets were plugged for this study.

Prior to the collection of samples, the faucets were opened and run for 72 hr to clear the lines of stagnant water and presumably provide the study with water characteristic of that in near-by watermains. Flow rates for each fixture were established and Table 10 illustrates the time required to achieve target flush volumes. Because of the rapid initial sampling frequency and errors associated with this type of sample collection, the flush volumes listed in the data tables are approximate values. After a set of samples was collected, the faucets were opened and run for 4-6 hr to clear the lines of stagnant water. The fixtures were shut off for approximately 8 hr to allow for the multiplication of endogenous bacteria prior to further sample collection.

The faucet bacterial flushing study was approached in three steps. The first step was to establish overnight (stagnant) levels of bacteria and to confirm that meaningful quantities of bacteria were achieved by monitoring bacterial levels of morning samples from each fixture on five consecutive mornings. The second step was to determine the range of flush volumes necessary to observe reductions of bacterial levels. This step was accomplished by sampling at target volumes (0, 1/8, 1/2, 1, 6, and 12 gallons) for each of the three fixtures. The third step was to expand the number of sampling points at specified flush volumes from 6 (in step 2) to 8 and to collect bacterial samples from each fixture on three successive days.

Results of Faucet Flushing Study

The results of the faucet flushing study are presented in Tables 11 through 13. The data from the "first water" samples (Table 11) demonstrated the variability of bacterial levels of flush water for the faucets and spray attachment. The SPC levels were scattered and ranged over three orders of magnitude. The SPC levels were of sufficient magnitude for the leaching study to be performed. Although it appeared that the faucet without aerator had lower levels of SPC than the other fixtures, data from subsequent flushing experiments failed to support this trend. When data from the initial flush volumes from all the sets of faucet flushing studies (Tables 11 through 13) were compared using the student "t" test and 90 percent significance level, no significant difference in the average first flush waters were observed for the three different types of faucet dispensers tested. The range SPC and endotoxin levels from the respective fixtures were typical of the levels found in earlier studies on laboratory control-loop stagnation samples.

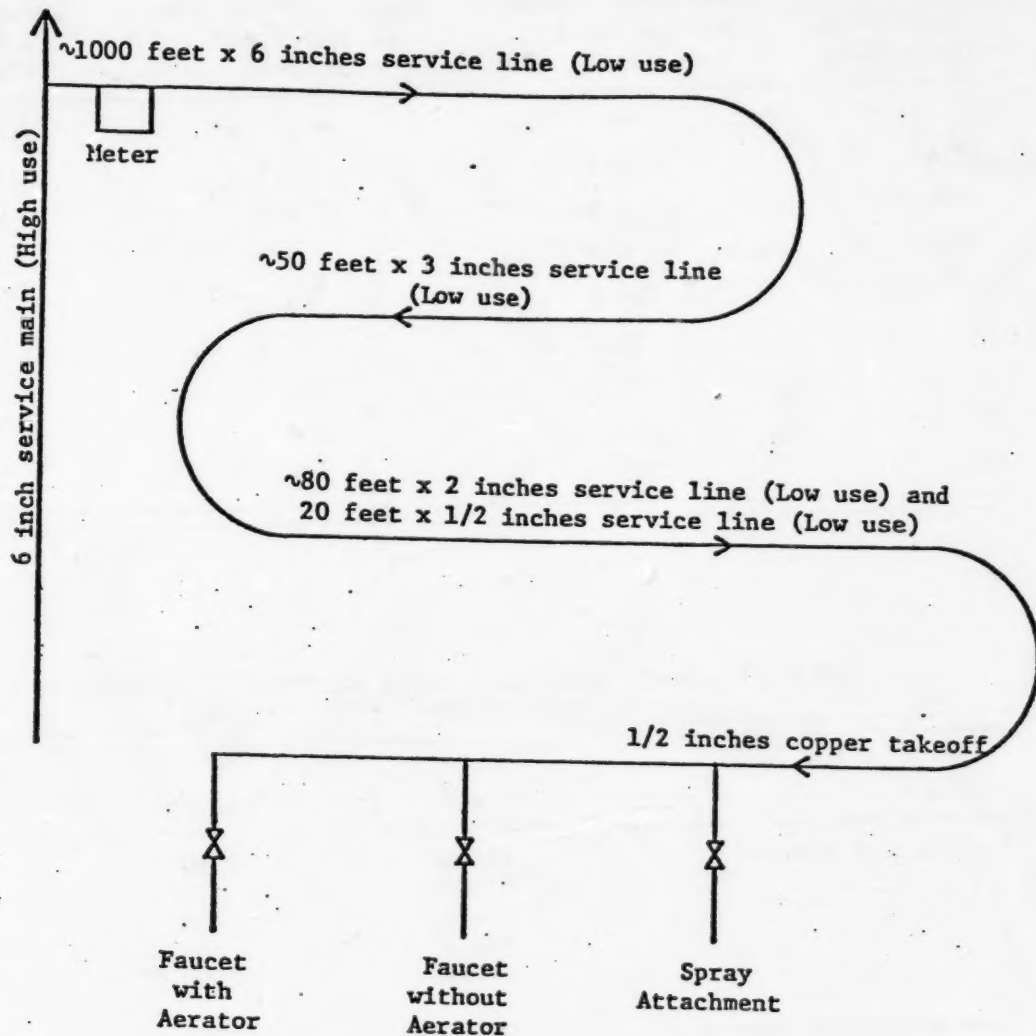


Figure 14.. Flow schematic of faucet test assembly used in the bacterial flushing study.

TABLE 10. FAUCET FLOW RATES AND TIMES REQUIRED TO FLUSH TARGET VOLUMES

Target flush volume (gal)	Faucet with aerator (1.8 gal/min) time (sec)	Faucet without aerator (2.9 gal/min) time (sec)	Spray attachment (2.6 gal/min) time (sec)
0	--	--	--
1/16	2.1	1.3	1.4
1/8	4.2	2.6	2.9
3/16	6.3	3.8	4.3
1/2	16.8	10.2	11.5
1	33.7	20.5	23.0
6	204	126	138
12	402	246	276
36	1212	738	828

TABLE 11. FIRST (STAGNANT) WATER BACTERIAL AND ENDOTOXIN LEVELS FROM COMMON KITCHEN FIXTURES

Fixture	Date	SPC/ml	Endotoxin (ng/ml)
faucet with aerator	8/4/80	10	1.6
	8/5/80	10	1.4
	8/6/80	240	1.2
	8/7/80	690	1.4
	8/8/80	2000	1.3
faucet without aerator	8/4/80	50	1.2
	8/5/80	100	1.3
	8/6/80	110	1.3
	8/7/80	11	1.3
	8/8/80	14	1.3
spray attachment	8/4/80	50	1.3
	8/5/80	90	1.4
	8/6/80	120	1.6
	8/7/80	78	1.8
	8/8/80	1300	2.0

TABLE 12. RANGEFINDING BACTERIAL AND ENDOTOXIN FLUSHING DATA
FROM COMMON KITCHEN FIXTURES

Fixture/date	Approximate flush volume (gallons)	SPC/ml	Endotoxin (ng/ml)
faucet with aerator/ 8-11-80	0	2200	0.8
	1/8	150	0.8
	1/2	160	0.9
	1	140	0.8
	6	58	1.0
	36	4	0.9
faucet without aerator/ 8-12-80	0	4200	1.0
	1/8	43	1.4
	1/2	42	1.2
	1	16	1.2
	6	42	1.0
	36	1	1.3
spray attachment/ 8-13-80	0	1500	16.0
	1/8	297	1.7
	1/2	37	1.1
	1	23	1.4
	6	44	1.0
	36	1	1.0

TABLE 13. EXPANDED FLUSHING BACTERIAL AND ENDOTOXIN DATA FROM COMMON KITCHEN FIXTURES

Approximate flushed (gallons)	8/25/80		8/26/80		8/27/80	
	SPC/ml	endotoxin	SPC/ml	endotoxin	SPC/ml	endotoxin
Faucet with Aerator						
0	440	5.3	--	10.5	1800	5.1
1/16	100	1.6	580	0.4	440	0.6
1/8	29	--	710	1.2	110	0.6
3/16	50	0.3	920	0.8	94	0.6
1/2	63	0.3	730	0.4	95	0.6
1	61	7.4	1400	0.7	50	0.6
6	360	2.2	100	0.5	3300	0.7
12	17	0.2	350	0.3	72	0.4
36	6200	0.8	6500	1.1	20100	1.3
Faucet without Aerator						
0	12000	0.9	13000	3.7	21000	1.5
1/16	1200	0.8	7100	0.8	6700	1.3
1/8	1800	0.9	6100	0.8	15000	1.1
3/16	3500	0.4	4200	0.8	12000	1.0
1/2	6500	0.7	--	0.8	18000	1.1
1	4000	0.4	6700	0.9	13000	1.3
6	1600	0.5	1200	0.5	5400	1.0
12	4400	0.4	4800	0.6	3900	0.9
36	5200	0.4	5200	0.6	4200	0.9
Spray Attachment						
0	3900	3.4	4000	0.9	4300	1.5
1/16	3100	0.6	3600	0.4	3000	0.9
1/8	3300	0.4	6100	0.6	3900	0.9
3/16	3900	0.4	4600	1.1	2400	0.6
1/2	770	0.5	3200	0.6	4600	1.1
1	243	0.5	7500	0.7	1200	1.0
6	6800	0.5	6300	0.8	5000	0.6
12	5500	0.4	8700	0.6	5400	0.6
36	5	0.3	6400	0.8	6600	0.6

The "range finding" results of the flushing experiments are presented in Table 12. Six samples were collected while 12 gallons of flush water were passed through each fixture. The majority of samples were collected after small flush volumes because of the expected quick flush-out of the faucet or sprayer. The same range of SPC levels were observed (10^1 , 10^2 , 10^3) as in the "first water" tests. An initial decrease of approximately one order of magnitude (10^3 to 10^2) in SPC levels was observed in most tests, and SPC levels then remained at approximately 10^2 levels throughout the processing of the amount (up to 6 gallons) of water usually dispensed in home use.

The results of the expanded flushing study are presented in Table 13. The range of SPC levels (10^1 to 10^4) demonstrated the variability of bacterial levels found in stagnant tap water. Part of the variability of SPC levels are explained by examination of the design characteristics of the water distribution system used in this study (Figure 14). The line (hold-up) volume prior to the feeder line of the distribution system was approximately 40 gallons. The feeder line was a 6-inch main approximately 600 feet long. After overnight stagnation, the water in this line was found to be chlorine free. Since each of the three fixture tests processed approximately 36 gallons, successive flushing tests were challenged with a different portion of feeder-line water (high in SPC). Consequently, the variation of SPC in the respective challenge waters was as great as, or greater than, the flushing variation that might be attributed to the various fixtures. Endotoxin levels did not reveal any significant correlation with respective SPC levels or demonstrate any statistically significant trends in the test.

Carbon Unit Bacterial Leaching Study

Overview

The idea that activated-carbon units for home water treatment support bacterial growth is supported in various studies. Bacterial growth in carbon units is a complex phenomenon and is affected by many factors including water matrix, strains of bacteria in water, level of disinfectant, unit flow design, and filter media characteristics (i.e., silver in carbon matrix, etc.). It is beyond the scope of this program to address all the factors affecting bacterial growth; the objective of this study element was to evaluate the first use leaching of bacteria from four carbon filters which had been challenged with New Orleans tap water.

Experimental Protocols

One filter type from each of the four classes was tested in duplicate trials. The four units were 1) Culligan SG-2 - line bypass, 2) AMF Cuno AP-117 - stationary, 3) Concept Bacteriostatic - faucet-mount, and 4) Puriton Bacteriostatic - pour-through. The Puriton and Concept units incorporated silver in the activated-carbon matrix in an effort to control bacterial growth. When each unit reached 75 percent of its rated capacity, bacterial leaching patterns were evaluated.

Each filter unit was operated at its normal flow rate, and sample collection was scheduled to provide an adequate number of data points at the expected leaching volume (0-3 gallons). Sample size (5-6 ml) was kept to a minimum to aid in rapid sample collection and to minimize the total volume of water processed.

Sample collection began immediately after the 8-hour overnight stagnation period; the unit was then cycled throughout the day and the sampling repeated the next day. Three control-loop samples were collected at selected amounts of processed water for comparison to unit effluent bacterial levels. Each sample was assayed for standard plate counts (SPC 1 = 48 hr at 35°C; SPC 2 = 120 hr at room temperature) and endotoxin.

Results of Bacterial Leaching Study

SPC, endotoxin, and flush volume data for the four filter types are presented in Tables 14 through 17. Each filter type was tested in duplicate, and each of the duplicate units were sampled on two successive days. Both control-loop and effluent data are reported.

Control-loop SPC levels were variable and ranged three orders of magnitude. Generally, the SPC levels were higher in the first flush waters and decreased as the flush volume increased. A statistical comparison was made between the average SPC of the "first water" from the units (0-0.25 gallons processed) and the average SPC of the remainder of the flushing volume (0.5 - 18 gallons) to confirm the hypothesis that the "first water" flush volumes represent a worst case bacterial situation. Average SPC levels dropped from 380 SPC/ml to 200 SPC/ml. This decrease was estimated to be significant at an 80 percent confidence level. Endotoxin values demonstrated no observable trends or correlations. These results and their interpretations are confounded by an apparent lack of consistency in the influent (control loop) SPC levels. Caution should be exercised in interpreting the bacterial and endotoxin data and drawing conclusions which exceed the limitations of the data.

Effluent SPC levels for the faucet-attached unit were lower than control-loop samples during the test period. This particular faucet-mount unit incorporated a submicron membrane filter as the last functioning element of the filter cartridge. This may account for the low SPC effluent levels after the first initial flush of the filter unit. The small size and holdup volume may also be a factor here. SPC data for the line bypass, stationary and pour-through units were variable and reflect the fact that respective control-loop and effluent SPC levels ranged between the same orders of magnitude.

Summary of Bacterial Leaching Studies

The bacterial leaching and flushing studies were designed to attempt to characterize the initial bacterial flushing from three types of water dispensing fixtures (faucet with aerator, faucet without aerator, and spray attachment) and four different types of activated carbon filters. This study

TABLE 14. BACTERIAL LEACHING DATA FOR THE LINE-BYPASS UNIT*

Test number/ date	Gallons processed	Control loop SPC/ml		Effluent SPC/ml		Control loop endotoxin (ng/ml)	Effluent endotoxin (ng/ml)
		48 hr	120 hr	48 hr	120 hr		
3A 9-4-79	0	36	50	59	66	--	3.2
	0.13			<1	<1		4.1
	0.25			40	18		2.9
	0.50			4	5		3.1
	1.0			<1	<1		2.1
	1.5			11	10		4.3
	2.0			6	11		2.6
	3.0	<1	<1	57	60	--	2.4
	18	23	31	<1	<1	3.0	1.3
3B 9-5-79	0	48	40	<1	<1	--	2.4
	0.13			<1	<1		2.4
	0.25			6	6		2.4
	0.50			11	12		1.5
	1.0			<1	<1		1.2
	1.5			7	10		2.6
	2.0			23	25		1.7
	3.0	<1	<1	3	4	--	1.5
	18	5	11	250	170	3.2	2.7
4A 9-9-79	0	240	440	900	830	--	4.7
	0.13			150	172		6.6
	0.25			39	61		4.0
	0.50			1	17		4.6
	1.0			<1	<1		4.2
	1.5			20	16		5.4
	2.0			400	420		6.9
	3.0	20	18	5	14	--	7.3
	18	4	4	17	19	--	8.0

(continued)

TABLE 14. (Continued)

Test number/ date	Gallons processed	Control loop SPC/ml		Effluent SPC/ml		Control loop endotoxin (ng/ml)	Effluent endotoxin (ng/ml)
		48 hr	120 hr	48 hr	120 hr		
4B	0	62	58	47	430		
9-10-79	0.13			11	700		
	0.25			<1	<1		
	0.50			3700	4300		
	1.0			200	540		
	1.5			650	500		
	2.0			120	160		
	3.0	7	50	31	140		
	18	520	780	36	510		

*Culligan, Model SG-2 nonsilver.

TABLE 15. BACTERIAL LEACHING DATA FOR THE FAUCET ATTACHED UNIT* (SILVERIZED MATRIX)

Test number/ date	Gallons processed	Control loop SPC/ml		Effluent SPC/ml		Control loop endotoxin (ng/ml)	Effluent endotoxin (ng/ml)
		48 hr	120 hr	48 hr	120 hr		
1A 9-18-79	0	19	73	390	820	5.8.	3.7
	0.13			<1	16		2.9
	0.25			<1	<1		2.1
	0.50			<1	24		2.9
	1.0			2	20		2.9
	1.5			<1	5		1.8
	2.0			<1	3		2.0
	3.0	15	46	<1	7	5.0	2.5
	18	110	8	<1	<1	2.5	1.9
1B 9-19-79	0	590	5600	110	990	3.5	3.7
	0.13			17	62		2.2
	0.25			3	1		1.2
	0.50			1	<1		1.5
	1.0			<1	<1		1.8
	1.5			4	2		2.2
	2.0			<1	<1		3.8
	3.0	87	140	1	<1	7.9	1.0
	18	5	14	<1	<1	4.1	0.7
2A 9-26-79	0	1900	7900	230	230	2.4	4.4
	0.13			10	5		2.8
	0.25			7	6		4.0
	0.50			1	4		2.6
	1.0			1	<1		1.8
	1.5			<1	<1		3.6
	2.0			<1	<1		3.2
	3.0	88	91	<1	<1	1.0	5.4
	18	160	240	<1	<1	0.7	1.6

(continued)

TABLE 15. (Continued)

Test number/ date	Gallons processed	Control loop SPC/ml		Effluent SPC/ml		Control loop endotoxin (ng/ml)	Effluent endotoxin (ng/ml)
		48 hr	120 hr	48 hr	120 hr		
2B	0	1000	1700	120	170	2.6	5.8
9-27-79	0.13			40	18		1.4
	0.25			<1	<1		2.2
	0.50			1	1		2.8
	1.0			<1	<1		3.6
	1.5			<1	<1		6.6
	2.0			1	1		1.6
	3.0	77	14	<1	<1	2.3	1.0
	18	11	7	<1	<1	1.6	3.2

*Concept Bacteriostatic.

TABLE 16. BACTERIAL LEACHING DATA FOR THE POUR-THROUGH UNIT*(SILVERIZED MATRIX)

Test number/ date	Gallons processed	Control loop		Effluent		Control loop endotoxin (ng/ml)	Effluent endotoxin (ng/ml)
		48 hr	120 hr	48 hr	120 hr		
7A 8-6-79	0	<1	<1	<1	22	1.5	3.0
	0.13				22		2.6
	0.25			<1	<1		3.3
	0.50			<1	<1		3.4
	1.0			61	37		--
	1.5			<1	<1		2.6
	2.0			41	20		3.6
	3.0	<1	10	<1	<1	1.6	1.4
	18	17	<1	120	51	3.2	1.6
7B 8-7-79	0	11	<1	11	200	1.3	1.8
	0.13			<1	<1		1.4
	0.25			4	17		2.2
	0.50			--	--		3.4
	1.0			<1	3		3.0
	1.5			4	13		2.3
	2.0			10	120		3.4
	3.0	55	110	<1	<1	2.2	2.2
	18	<1	41	18	5	1.6	2.2
8A 8-28-79	0	17	17	<1	<1	3.4	3.8
	0.13			<1	<1		2.3
	0.25			37	34		2.2
	0.50			19	38		2.8
	1.0			<1	<1		1.7
	1.5			11	13		2.1
	2.0			<1	<1		2.8
	3.0	<1	<1	28	35	2.8	3.0
	18	<1	28	10	13	0.6	1.5

(continued)

TABLE 16. (Continued)

Test number/ date	Gallons processed	Control loop SPC/ml		Effluent SPC/ml		Control loop endotoxin (ng/ml)	Effluent endotoxin (ng/ml)
		48 hr	120 hr	48 hr	120 hr		
8B	0	40	5	50	11	2.4	2.4
8-29-79	0.13			37	3		3.0
	0.25			130	11		4.2
	0.50			82	<1		2.0
	1.0			39	<1		1.7
	1.5			16	52		2.8
	2.0			9	<1		2.8
	3.0	30	<1	43	<1	3.0	2.5
	18	57	10	3	<1	4.2	1.3

*Puriton Bacteriostatic.

TABLE 17. BACTERIAL LEACHING DATA FOR THE IN-LINE STATIONARY UNIT*

Test number/ date	Gallons processed	Control loop SPC/ml		Effluent SPC/ml		Control loop endotoxin (ng/ml)	Effluent endotoxin (ng/ml)
		48 hr	120 hr	48 hr	120 hr		
5A 7-17-79	0	60	60	120	120	3.8	3.6
	0.13			<10	110		3.0
	0.25			130	250		4.0
	0.50			130	<10		4.1
	1.0			400	440		3.4
	1.5			40	220		1.8
	2.0			160	130		2.1
	3.0	10	<10	230	60	2.0	4.0
	18	210	210	90	10	2.1	1.9
						--	
5B 7-18-79	0	5	5	1300	1600		6.8
	0.13			1800	1400		5.9
	0.25			2600	2200		5.0
	0.50			1600	1400		7.4
	1.0			120	250		3.2
	1.5			50	55		5.2
	2.0			51	480		7.6
	3.0	3	2	48	45	--	3.8
	18	2	2	5	8	--	4.6
6A 8-20-79	0	380	720	530	290	1.8	1.9
	0.131			87	149		1.5
	0.25			700	470		3.6
	0.50			63	220		3.0
	1.0			140	390		2.1
	1.5			140	180		2.1
	2.0			130	96		2.0
	3.0	40	160	14	14	1.5	3.5
	18.1	57	70	140	45	1.8	4.0

(continued)

TABLE 17. (Continued)

Test number/ date	Gallons processed	Control loop SPC/ml		Effluent SPC/ml		Control loop endotoxin (ng/ml)	Effluent endotoxin (ng/ml)
		48 hr	120 hr	48 hr	120 hr		
6B	0	<1	<1	27	30	4.7	4.7
8-21-79	0.138			49	53		4.7
	0.25			140	1		1.8
	0.50			<1	5		3.0
	1.0			<1	10		1.6
	1.5			15	34		3.8
	2.0			59	24		2.0
	3.0	<1	<1	3	7	2.6	1.5
	18.1	1	1	1	<1	3.5	5.1

*ANF Cuno, Housing 1M, Cartridge AP-117; nonsilver.

element was the first attempt to evaluate the filter unit effluent SPC levels as a function of time (flushing). Results of the unit flushing study support the assumption of "first water" representing worst case bacterial situations. Statistical examination of the data indicated the "first" waters exhibited higher SPC levels than subsequent flush waters (at an 80 percent confidence level). This has been the assumption made throughout the study and is the basis for routinely collecting bacterial samples as first water samples.

Monitoring the time or flush volume dependence of SPC levels enables one to observe secondary effects which may have been occurring in the carbon filters. An example of one secondary effects observed appears to be the apparent low levels of SPC bacteria in the Concept filter effluent water after a short initial flush time. This was probably due to a design feature of this particular filter. These characteristics of the filters have not been evaluated routinely and would not normally be observed with studies focusing on "first water" samples. Two observations were drawn from the faucet flushing experiments. Examination of first flush waters from the faucets indicate no significant difference between the three type water fixtures. The data was challenged with the student "t" test at both 90 percent and 80 percent confidence levels. The difference in SPC levels for the first 0.25 gallon of each fixture flush water was not significant at either confidence level.

Another notable observation from the faucet flushing study was the variability of the bacterial quality of the source water. This variability, in some situations, is larger than the responses being monitored. The problem of "control" water SPC variability has been present throughout the study and often complicates data interpretation. The problem of SPC level variability, the limited scope of the flushing studies, and the level of data scatter prevent other meaningful conclusions from being drawn.

SPENT CARBON STUDY

Overview of Spent Carbon Study

The objective of this study was to determine what types of organic chemicals are adsorbed and retained by the activated carbon in home water treatment units. Although an entire research project could be devoted to this effort, time and cost limitations required that relatively quick and general analytical methods for sample concentration, clean-up, and GC/MS analysis be employed during the present study. Activated carbon from three different types of home water treatment units (line bypass - Aqualux, stationary - Sears, and faucet-mount - Hurley) was analyzed after the respective units had been tested in a series where the challenge water included the spiked halogenated organics. Details of the experimental procedures are described in the Addendum Report: Surface Water Supply Study - Problems and Evaluation.

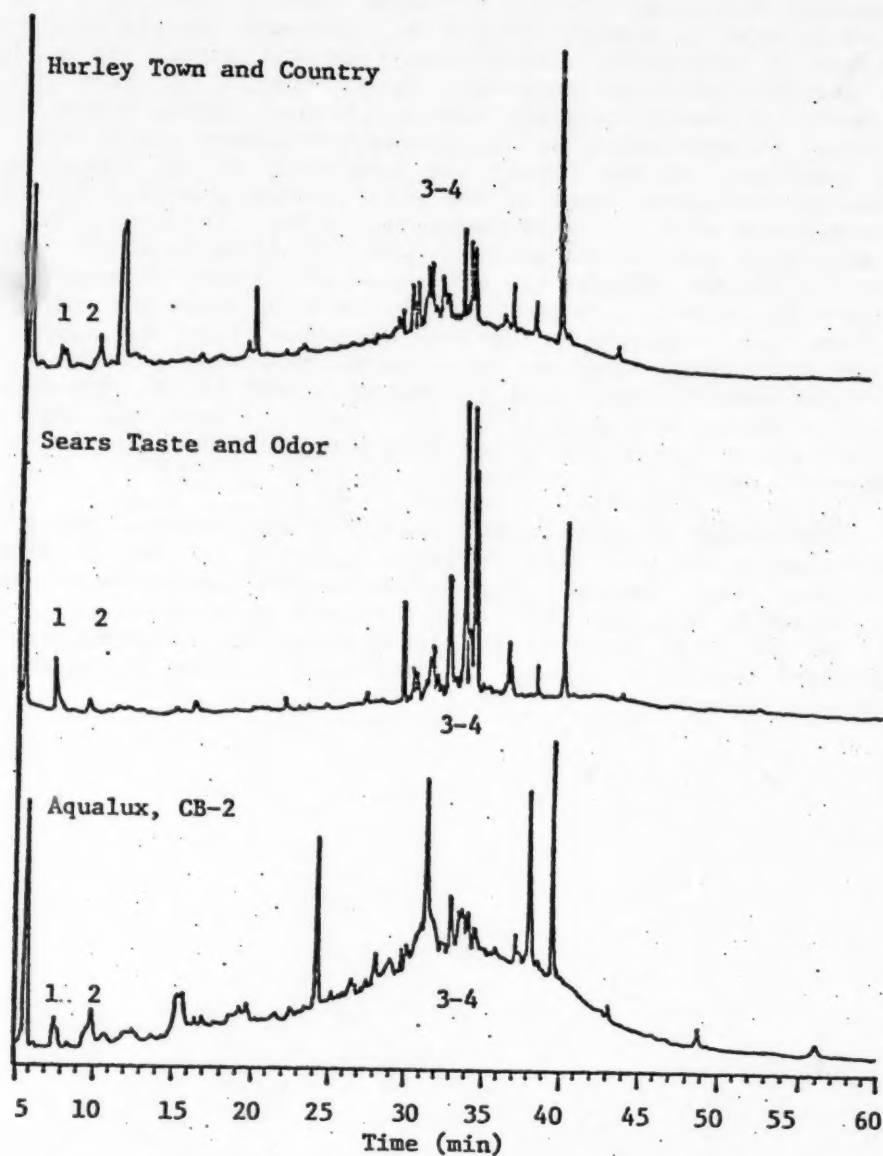
Results of the Spent Carbon Study

Two factors are important in the interpretation of the GC/MS data of the spent-carbon study. First, since the experimental design of the study did not permit the collection of absolute quantitative data, only relative amounts (within each sample) of the various compounds were indicated. Second, tentative identifications of the various compounds were made by a computer search of mass spectral libraries and manual interpretation. Consequently, with a few exceptions, only classes of organic compounds were identified in this study since confirmation of compound identities with authentic standards was beyond the scope and cost limitation of this program.

The compounds classified as halogenated organics (spiked HO) in this study were too volatile to be satisfactorily recovered by Soxhlet extraction procedures (except chlordanes, $C_{10}Cl_6$, and $C_{12}H_4Cl_2$). The volatile components of the spiked New Orleans tap water were expected to be recovered by the purge-and-trap procedure used on water containing the submerged spent-carbon. In fact, only chloroform and dichlorobromomethane were detected in substantial quantities; trace levels of carbon tetrachloride, trichloroethylene, tetrachloroethylene, and 1,1,1-trichloroethane were also observed. These observations indicated the following phenomena or conditions:

1. $CHCl_3$ and $CHCl_2Br$ were detected because they were present in the challenge water at higher levels ($CHCl_3$ ~100 ppb, $CHCl_2Br$ ~20 ppb) than the other THM ($CHClBr_2$ and $CHBr_3$) and because they were the least adsorbed THM on activated carbon (i.e., they were the first to desorb off the carbon and be detected).
2. CCl_4 was not strongly adsorbed by activated-carbon and since its concentration in the challenge water was between 10 and 20 ppb, CCl_4 was detected only in trace amounts.
3. 1,1,1-trichloroethane, like $CHCl_3$ and CCl_4 , was not strongly adsorbed by activated-carbon; therefore, it was detected only in trace amounts.
4. Although high levels (i.e., 50 ppb) of trichloroethylene and tetrachloroethylene were spiked into the challenge water, these compounds were detected only in trace amounts from the purged activated-carbon samples because they were strongly adsorbed by the activated carbon.

Figure 15 illustrates the respective total ion chromatograms (TIC) of the extracts from the spent carbon from each of the three types of home water treatment units. Each TIC exhibits the semivolatile compounds Soxhlet extracted from approximately 50 g of spent carbon. The similarity of each TIC was expected and confirms the fact that activated carbon removes a variety of organic compounds from water. The compounds, or class of compounds, represented in Figure 15 are classified as semivolatile and were also represented by NPTOC and NPCAOX data. Tables S86 through S88 (Phase 3/Final



Tentative compound identification: 1) 2-butoxy ethanol; 2) phenol; 3) complex mixture of biologically derived acids, alcohols, esters, and hydrocarbons; and 4) halogenated compounds (most likely chlordane derivatives or isomers).

Figure 15. Comparison of the spent-carbon extracts from three types of home water treatment units.

Report - Supplemental Data) list the tentative identifications of the compounds extracted off the activated carbon. Generally, the respective extracts were a complex mixture of compounds representing the following classes of compounds: 1) biologically-derived acids, esters and alcohols, 2) chlorine-containing compounds (most likely chlordane derivatives or isomers), 3) common solvents such as phenols, glycol ethers, alcohols, and ketones, 4) phthalates, and 5) hydrocarbon-alkanes and alkenes. Because of the complexity of the extract and simplicity of the extraction scheme and clean-up procedures, most of the mass spectra generated by GC/MS analysis were mixtures of two or more compounds. A characteristic element of each TIC is the large hump in the middle of the TIC (from 20-45 min retention time): this TIC pattern reflects the co-elution of the many compounds present in the respective extracts. Generally, the coeluting compounds which make up this pattern are biologically derived compounds such as humic acid, alkyl alcohols, acids, ester, and long chain hydrocarbons (alkanes and alkenes). Also included in this mass of compounds may be the organics present in bacteria which were adsorbed on the carbon. As expected, there was evidence of the adsorption of the spiked chlordane and other halogenated organics in the mass spectra.

Additional factors which cannot be overlooked in the GC/MS study of spent carbon are that organics unload (desorb) off the carbon during normal use and that control samples of unused carbon were not analyzed. Consequently, the compounds identified were those which were either present in the challenge water to the greatest extent, adsorbed most strongly by activated carbon, or present on the activated carbon in the new units (least likely occurrence).

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